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(54) **METHOD OF SCREENING CANDIDATE PROTECTIVE, POTENTIATING, OR INHIBITING SUBSTANCES**

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(56) **References Cited**

**U.S. PATENT DOCUMENTS**

4,769,331 9/1988 Roizman et al. .... 435/172.3  
5,328,688 \* 7/1994 Roizman .... 424/205.1  
5,585,096 \* 12/1996 Martuza et al. .... 424/93.2

**FOREIGN PATENT DOCUMENTS**

243155 10/1987 (EP).  
453242 10/1991 (EP).  
WO 92/04050 3/1992 (WO).

**OTHER PUBLICATIONS**

Mulligan, R.C. "The Basic Science of Gene Therapy" *Science*, vol. 260: 926-930, May 14, 1993.\*  
Coghlan, A. "Gene Dream Fades Away" *New Scientist* p. 14-15, Nov. 25, 1995.\*  
Brown, D. "Gene Therapy Oversold By Researchers, Journalists" *The Washington Post*, A22 Friday, Dec. 8, 1995.\*  
Ackermann et al., *J. Virol.*, 52:108-118 (1984).  
Ackermann et al., *J. Virol.*, 58: 843 (1986).  
Barinaga, M., *Science*, 754-756 (1994).  
Centifano-Fitzgerald et al., *J. Exp. Med.*, 155: 475 (1983).  
Chou and Roizman, *Cell*, 41:803-811 (1985).  
Chou and Roizman, *J. Virol.*, 57: 629-637 (1986).  
Chou and Roizman, *J. Virol.*, 64:1014-1020 (1990).  
Chou and Roizman, *Biochemistry*, Report, Jan. 8, 1991.  
Chou and Roizman, *J. Cell Biochem.*, Keystone Symposia, Supplement 10C, Feb. 21-Mar. 2, 1992, Abstract N303, p. 136.  
Chou and Roizman, *PNAS*, 89: 3266-3270, Apr. 1992.  
Chou et al., *Science*, 250: 1262-1266 (1990).  
Clem et al., *Science*, 254: 1388-1399, Nov. 29, 1991.  
Corey and Spear, *N. Eng. J. Med.*, 314: 686-691 (1986).  
DeLuca et al., *J. Virol.*, 56: 558-570 (1985).

Ejercito et al., *J. Gen. Virol.*, 2: 357-364 (1986).  
Gagliardini et al., *Science*, 263: 826-828 (1994).  
Gregory et al., *Nature*, 349: 612-614 (1991).  
Hammang, J. P., Bristol-Meyers Squibb, Phar. Research Inst., Research Report Feb. 7, 1992.  
Hayward et al., *Proc. Natl. Acad. Sci. USA*, 1972: 4243-4247 (1975).  
Henderson et al., *Cell*, 65: 1107-1115 (1991).  
Hones and Roizman, *J. Virol.*, 12: 1347-1365 (1973).  
Hubenthal-Voss et al., *J. Virol.*, 62: 454 (1988).  
Itoh et al., *Cell*, 66: 233-243 (1991).  
Javier et al., (*J. Virol.*, 65: 1978, 1987) and Thompson et al., *Virology*, 1972: 435 (1989).  
Johnson et al., *Neurobiol. of Aging*, 10: 549-552 (1989).  
Katz et al., *J. Virol.*, 64: 4288-4295.  
KYTE et al., *J. Mol. Biol.*, 157: 105-132 (1982).  
Loo et al., *J. Neuroscience Research*, 28: 101-109 (1991).  
Lord et al., *Nucleic Acid Res.*, 18: 2823 (1990).  
Mackem and Roizman, *J. Virol.*, 44: 934-947 (1982).  
Markert et al., Dept. of Neuro., Harvard Med. School, Research Manuscript, 18 pgs. (1992).  
McGeoch et al., *J. Gen. Virol.*, 64: 1531-1574 (1988).  
Meignier et al., *J. Infect. Dis.*, 158: 602 (1988).  
Peppel and Baglioni, *BioTechniques*, 9: 711-712 (1990).  
Post and Roizman, *Cell*, 25: 227 (1981).  
Rawson et al., *J. Cell Biol.*, 113: 671-679 (1991).  
Renfranz et al., *Cell*, 66: 713-729 (1991).  
Roizman, *Field's Virology*, 2 ed., 64: 1787-1793 (1990).  
Roizman, *Field's Virology*, 2 ed., 5: 87-94 (1991).  
Roller and Roizman, *J. Virol.*, 65: 5873-5879 (1991).  
Ryder et al., *J. Neurobiol.*, 21: 356-375 (1990).  
Sentman et al., *Cell*, 67: 879-888, Nov. 29, 1991.  
Snyder et al., *Cell*, 68: 33-51 (1992).  
Strasser et al., *Cell*, 67: 889-899, Nov. 29, 1991.  
Taha et al., *J. Gen. Virol.*, 70: 705 (1989).  
Wadsworth et al., *J. Virol.*, 15: 1487-1497 (1975).  
Whitlay et al., *J. Clin. Invest.*, 91: 2387-2843, (1993).  
Williams, *Cell*, 65: 1097-1098 (1991).  
Williams, *Cell*, 85: 1097-1098, (1991).

\* cited by examiner

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(57) **ABSTRACT**

The present invention relates to methods of treatment of programmed cell death (apoptosis) through the use of the HSV-1 gene  $\gamma_134.5$  or the product of its expression, ICP34.5. The gene and its expression have been demonstrated to be required for HSV-1 neurovirulence, and in particular, to act as an inhibitor of neuronal programmed cell death which allows for viral replication. Use of the gene therapy, or the protein itself, can be expected to result in inhibition of programmed cell death in various neurodegenerative diseases. This invention also relates to novel vectors for gene therapy, including modified herpes virus. Methods are presented for conducting assays for substances capable of mimicking, potentiating or inhibiting the expression of  $\gamma_134.5$  or the activity of ICP34.5. Also, methods are disclosed for the treatment of tumorigenic diseases, including cancer, and for treatment of herpes and other viral infections using inhibitors of  $\gamma_134.5$  expression or ICP34.5 activity.

**Fig. 1a**

**Fig. 1b**

**Fig. 1c**

**Fig. 1d**

Arg Val Arg His Leu Val Val Trp Ala Ser Ala Arg Leu Ala Arg Arg Gly Ser Trp Ala Arg Glu Ala  
Ser Gly Cys Ala Thr Trp Ser Gly Pro Arg Pro Pro Ala Trp Arg Ala Ala Arg Gly Pro Ala Ser Gly  
224

Asp Arg Ala Arg Phe Arg Arg Val Ala Glu Ala Val Ile Gly Pro Cys Leu Gly Pro Glu Ala Arg  
Pro Thr Gly Leu Gly Ser Gly Ala Gly Trp Arg Arg Pro Arg Arg Ser Ser Gly Arg Ala Trp Gly Pro Arg Pro  
249

Lys

263

Ala Arg Ala leu Ala Arg Gly Ala Gly Pro Ala Asn Ser Val 10c  
Val Pro Gly Pro Trp Pro Ala Glu Pro Ala Arg Arg Thr Arg Ser Asn Val Thr Pro Glu Ala Ala Trp Val Phe

Arg Gly Ala Pro Gly Ser Ser Ala Pro Ser Arg Ser Pro Glu Arg Arg Trp Glu Pro Arg Ile Tyr Thr Leu  
Gly Ala Ser Pro Pro Ser Gly Ile Gly Pro Pro Arg Gly Arg Asp Trp Pro Ile Gly Arg Gly Arg Gly Ile Gly  
Ala Arg Pro Thr Ser Val Arg Arg Val Phe Gly Ala Arg Pro Ile Gly Arg Glu Leu Pro Pro Asn Gly Pro Gly  
Arg Pro Leu Pro Gly Met Val Ile Lys Asn Leu Glu Ala Ala Phe Arg Phe Pro Val Trp 0c

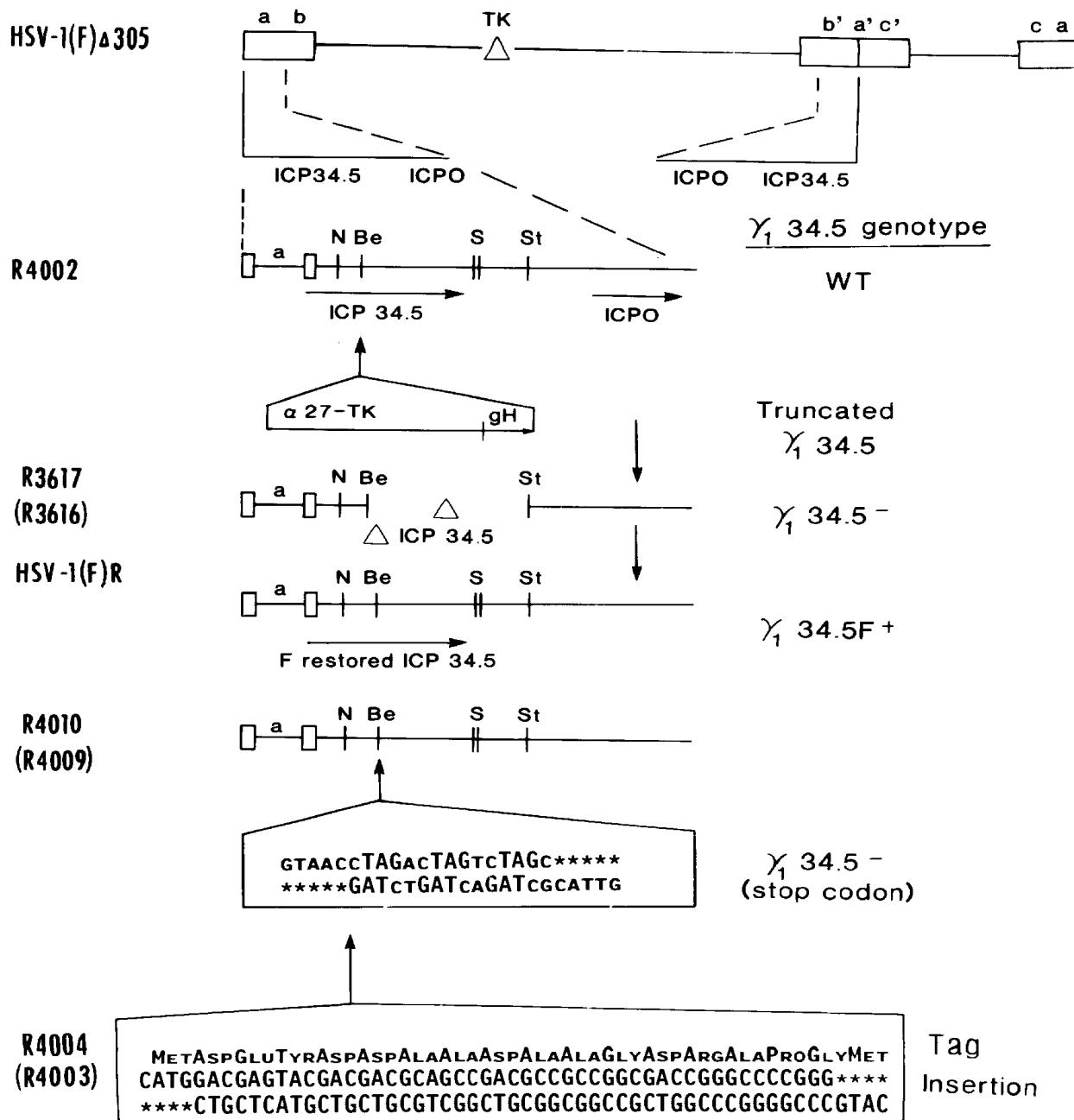
**Fig. 2**

Fig. 3a

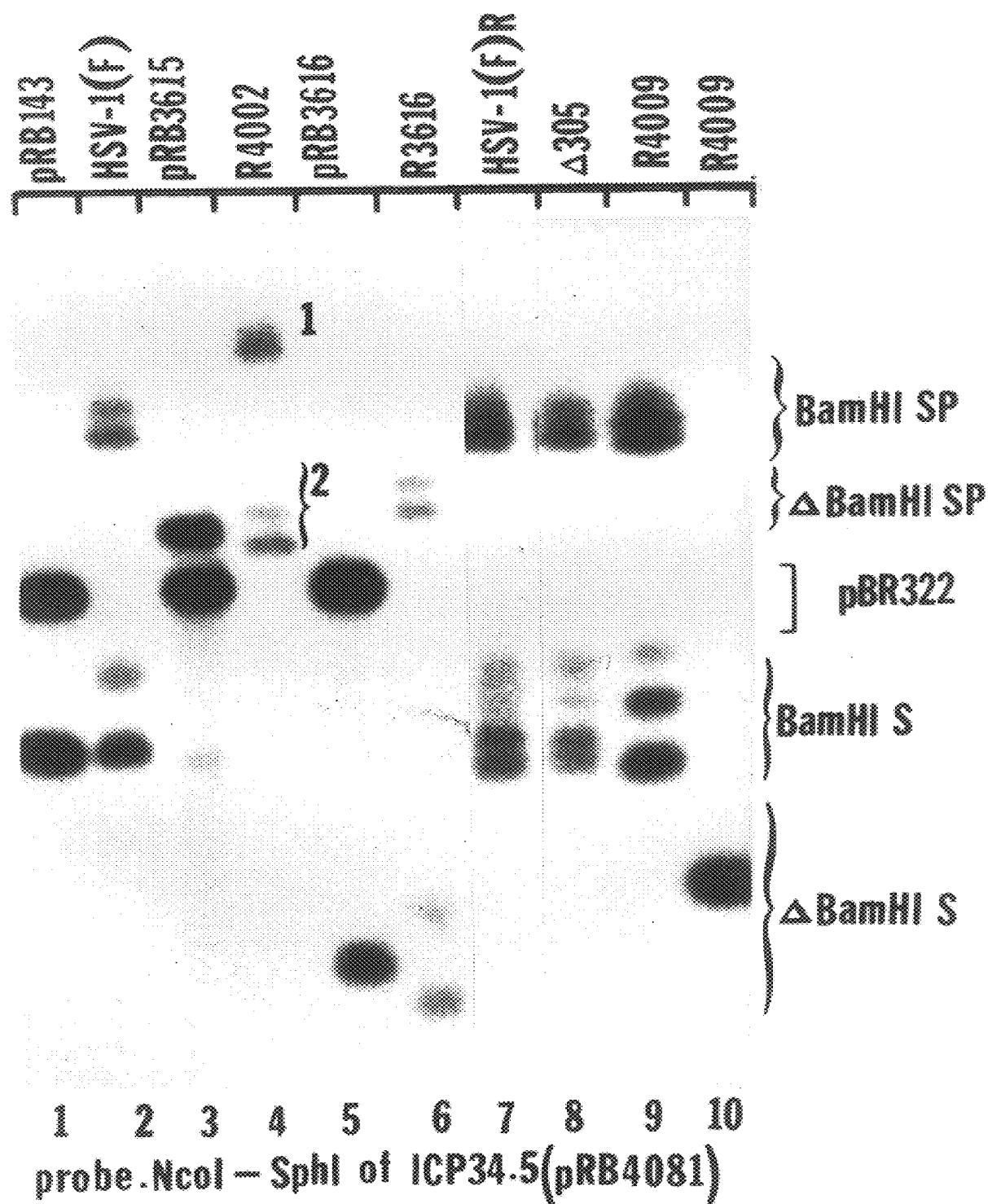
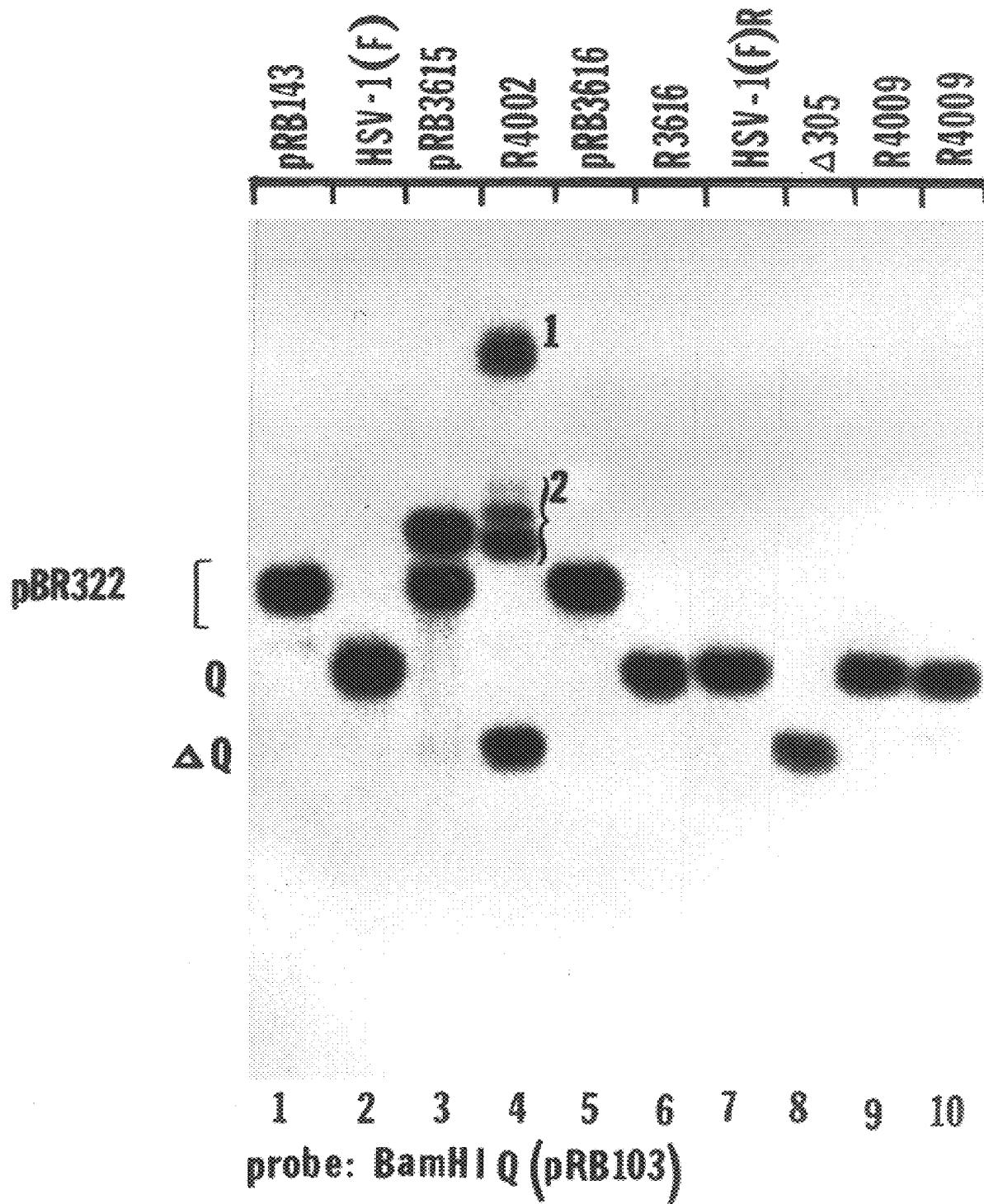
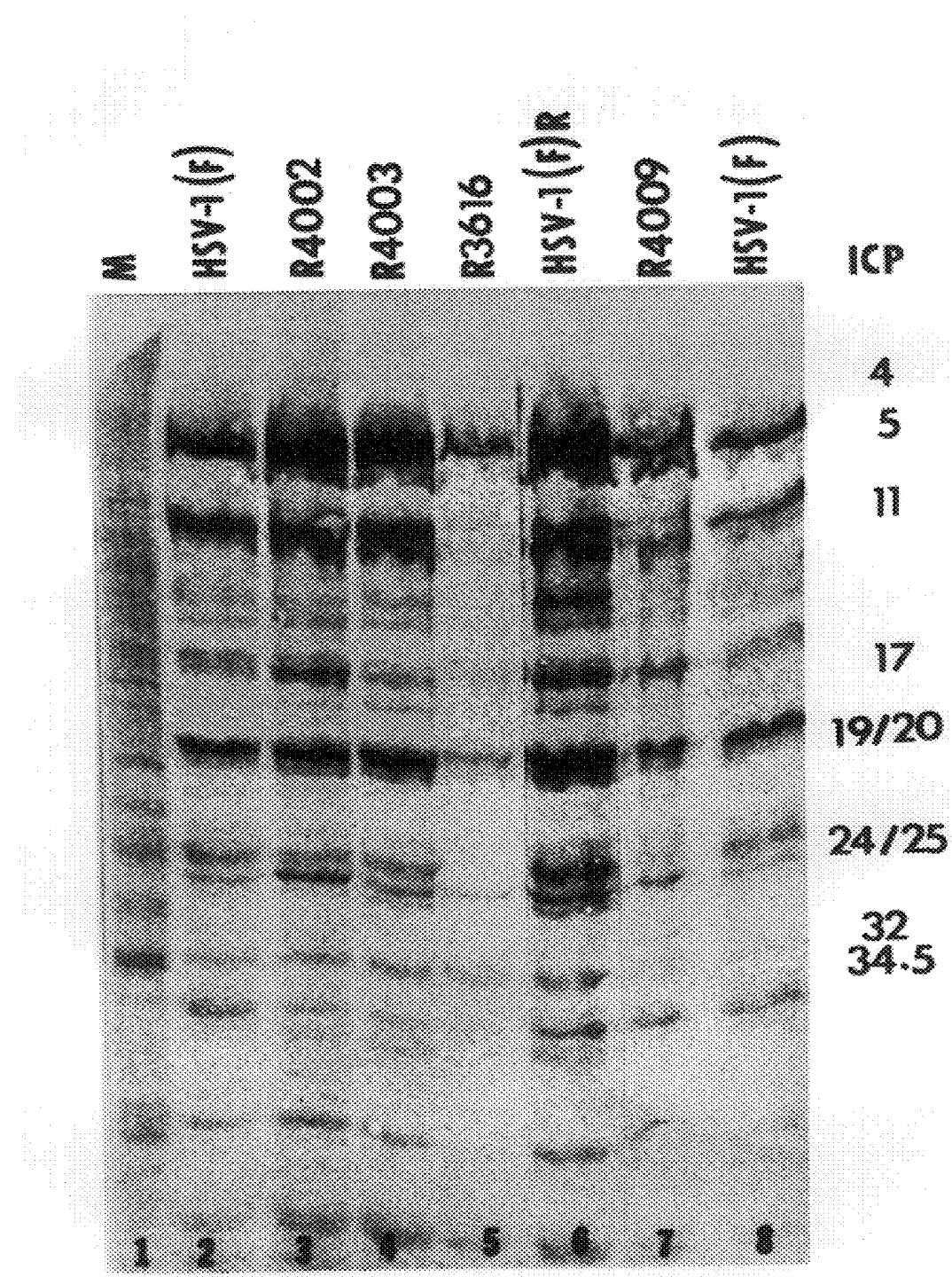
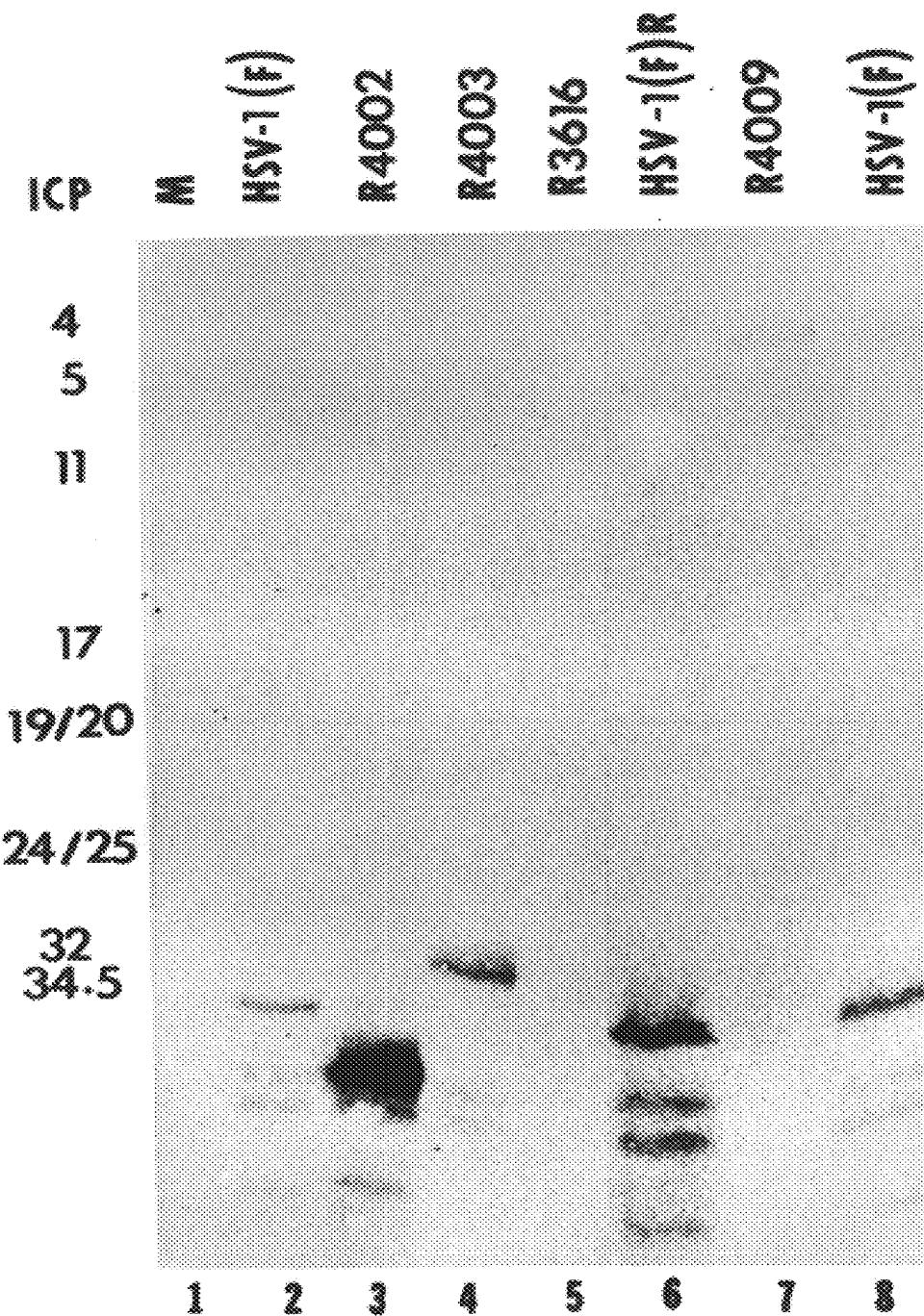
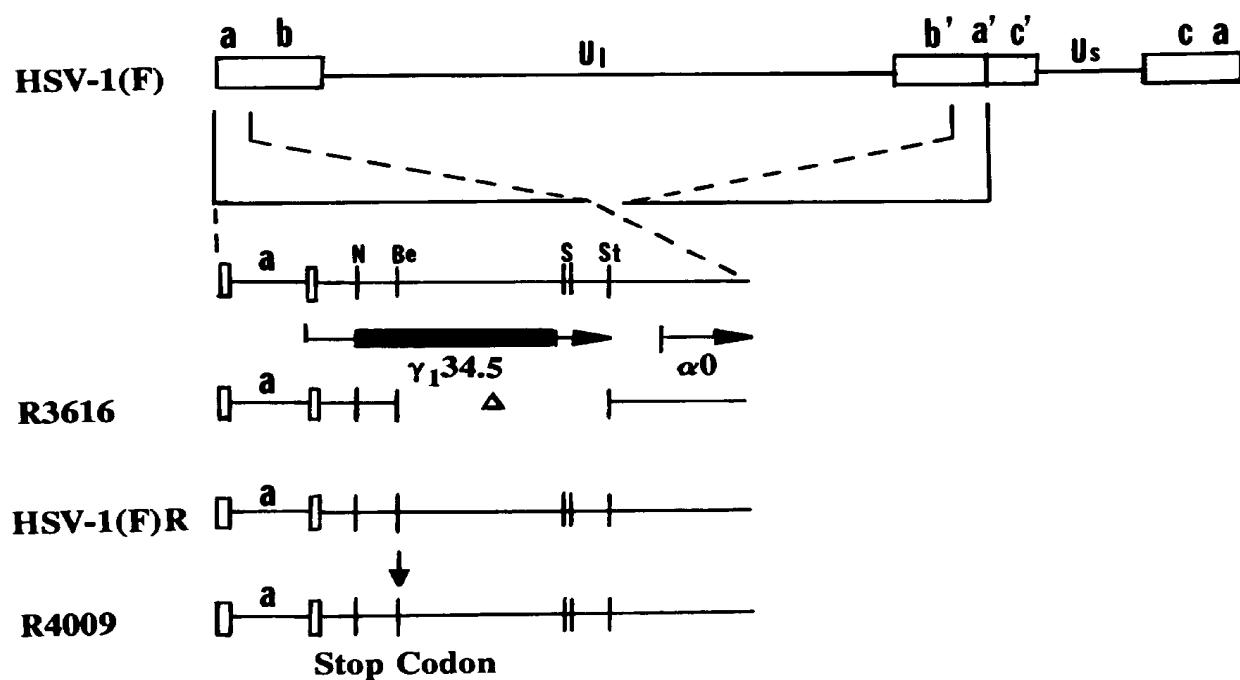


Fig. 3b



**Fig. 4a**

**Fig. 4b**

**Fig. 5**

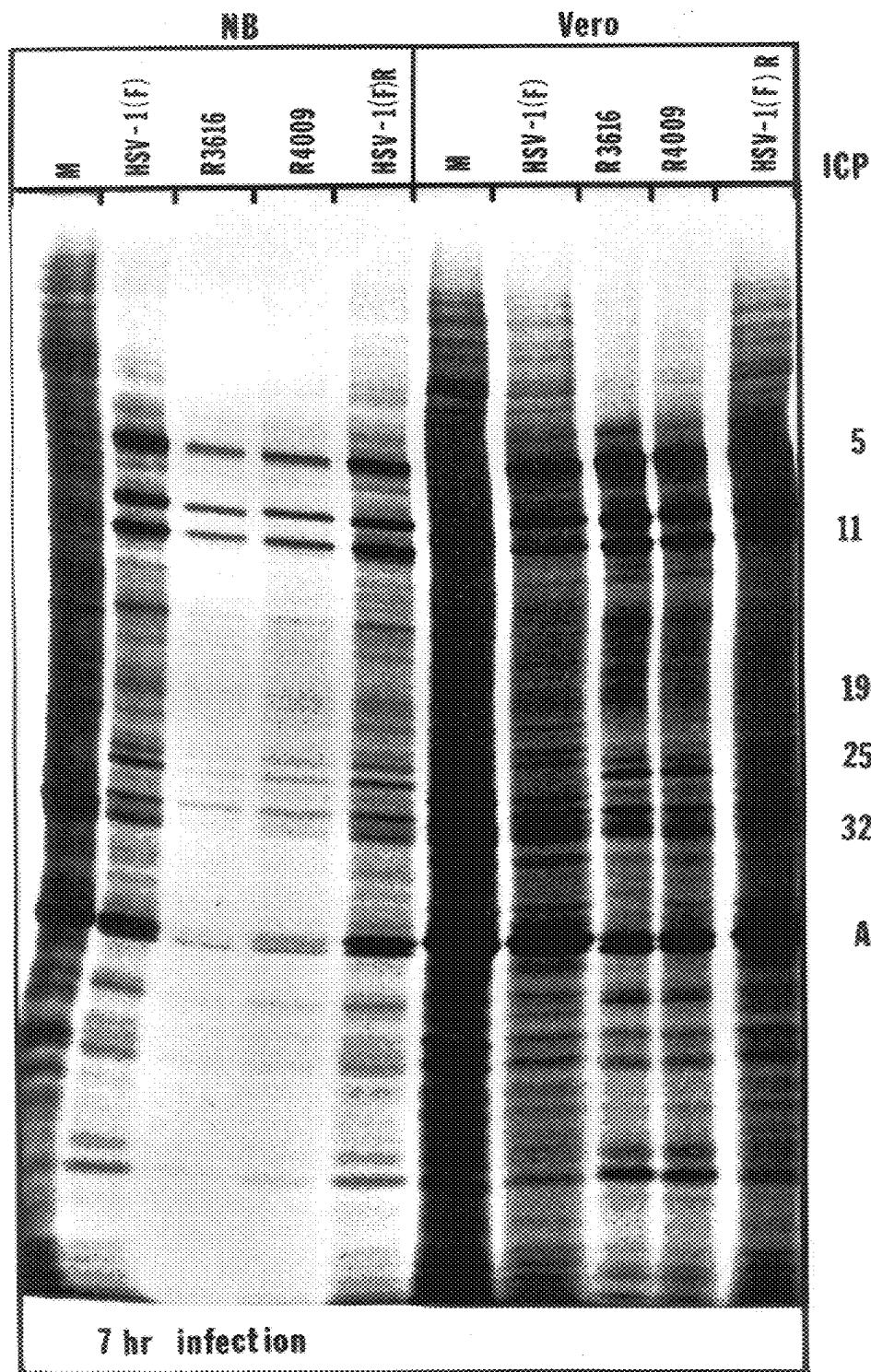


Fig. 6a

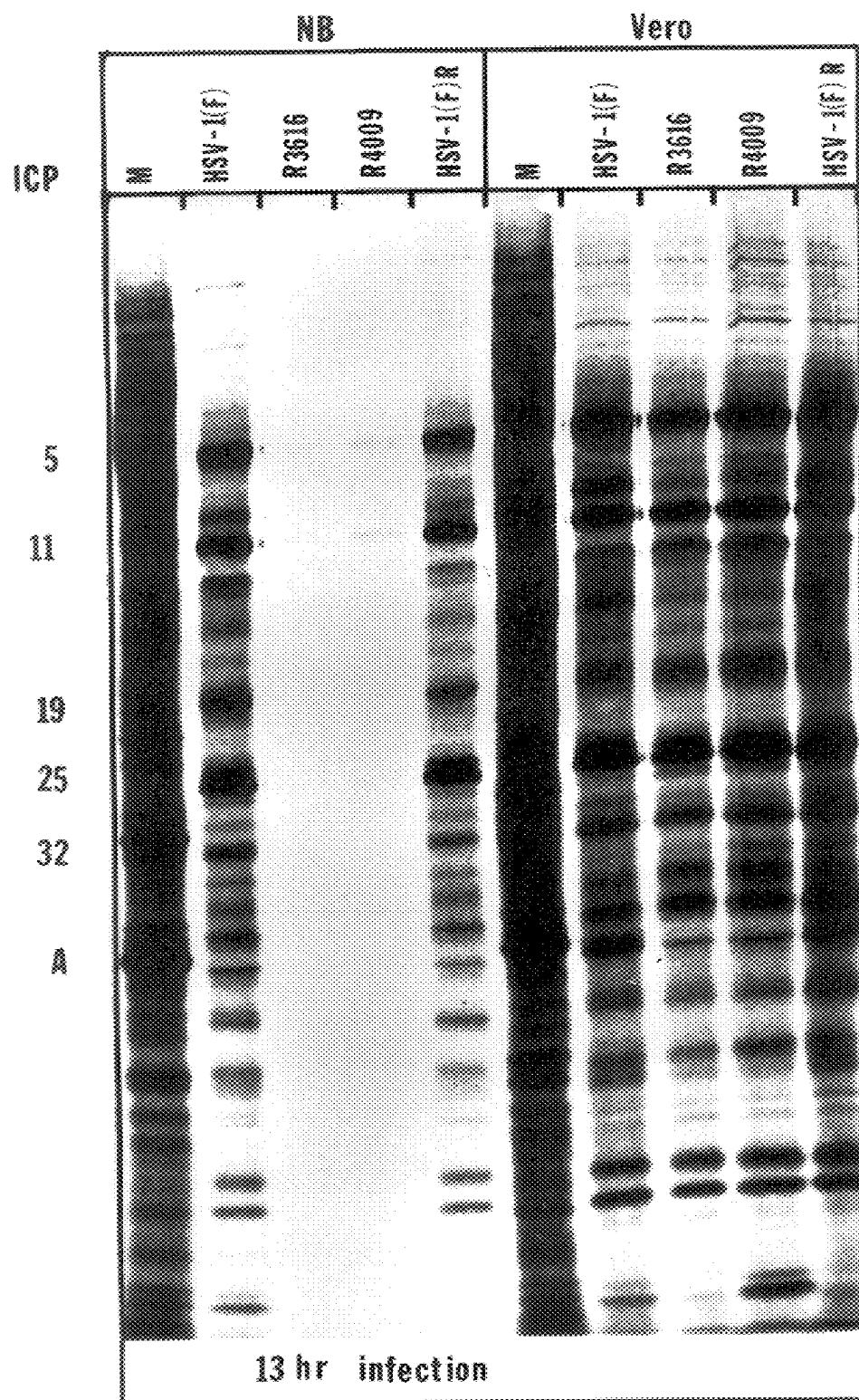
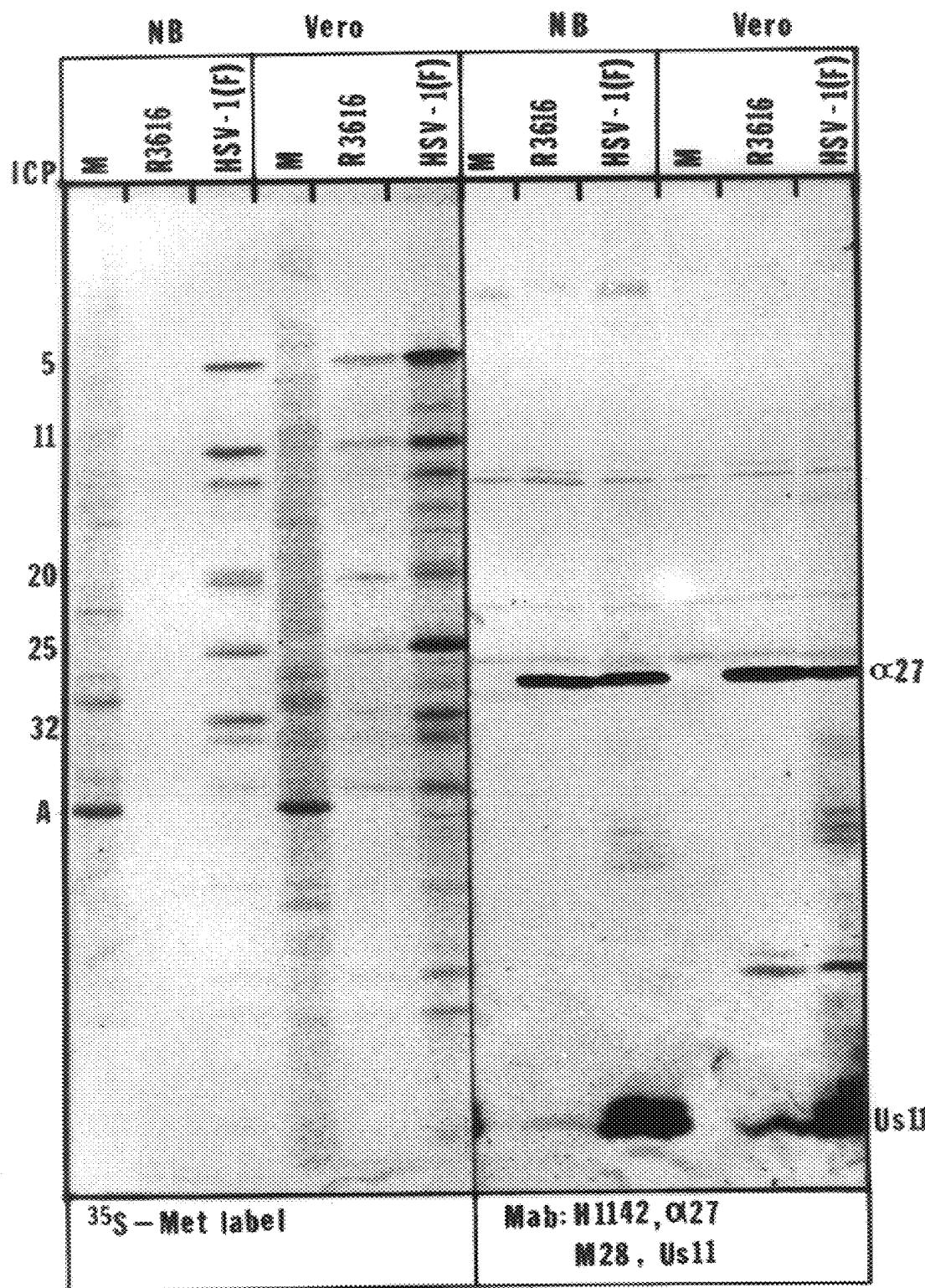


Fig. 6b

Fig. 7a



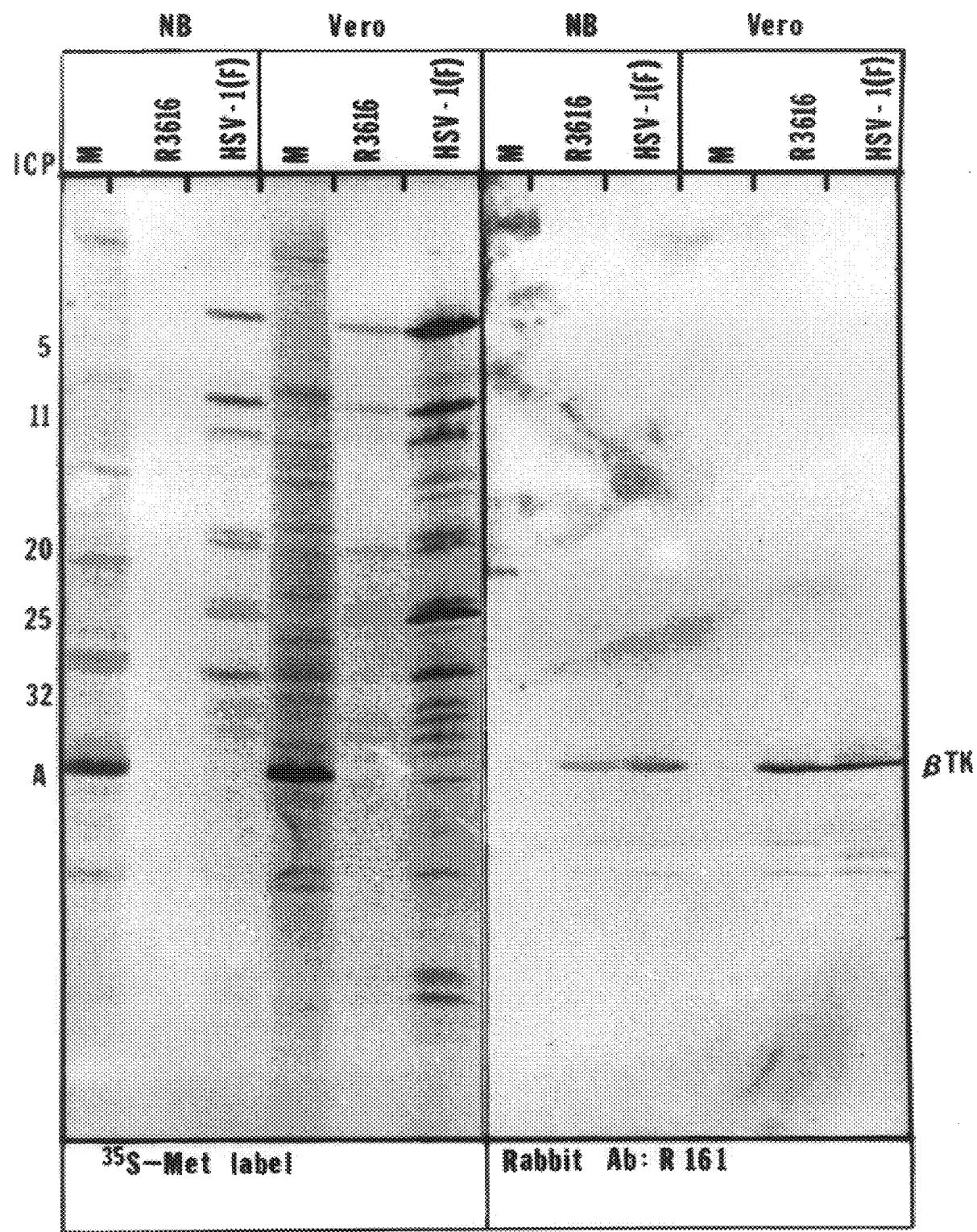
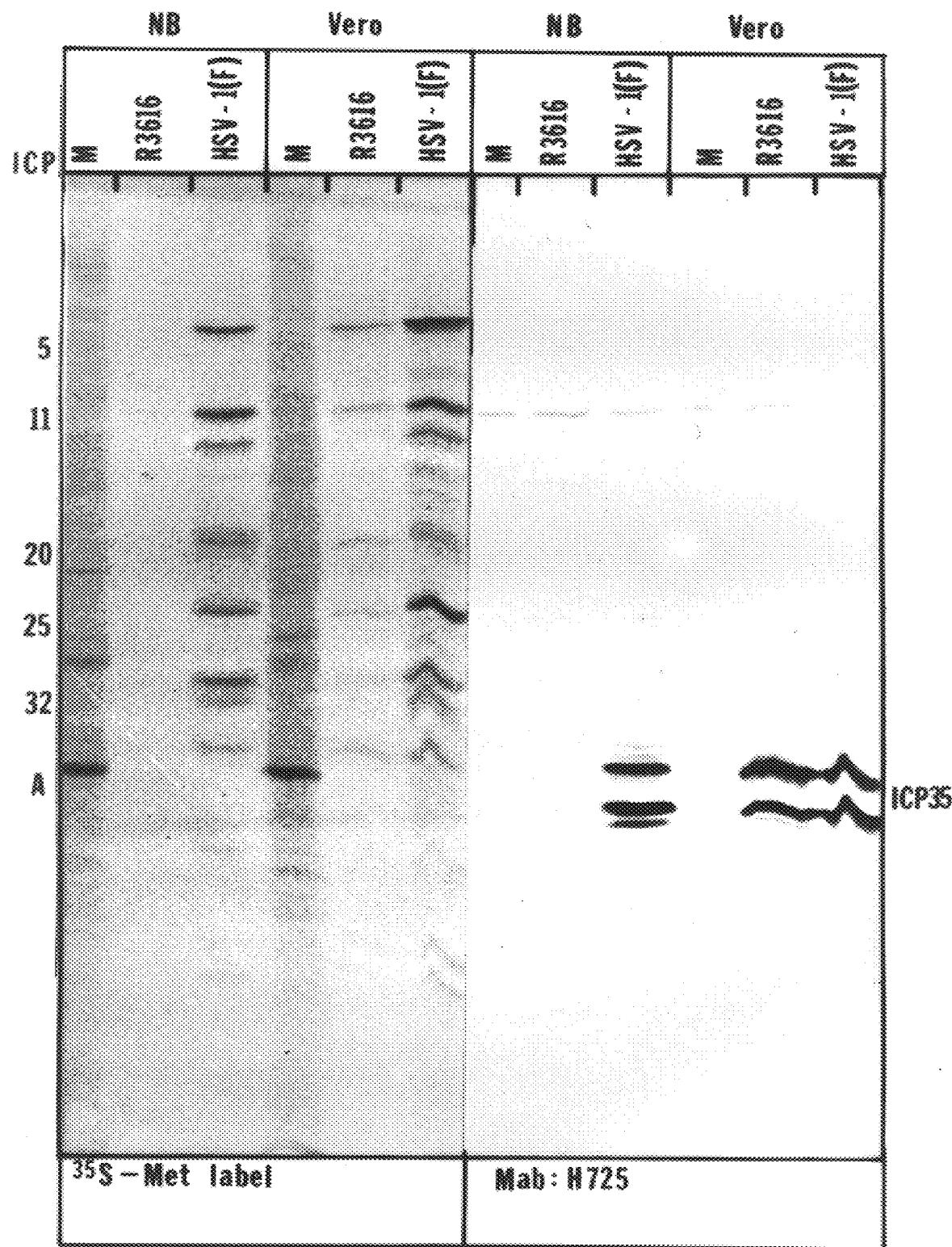
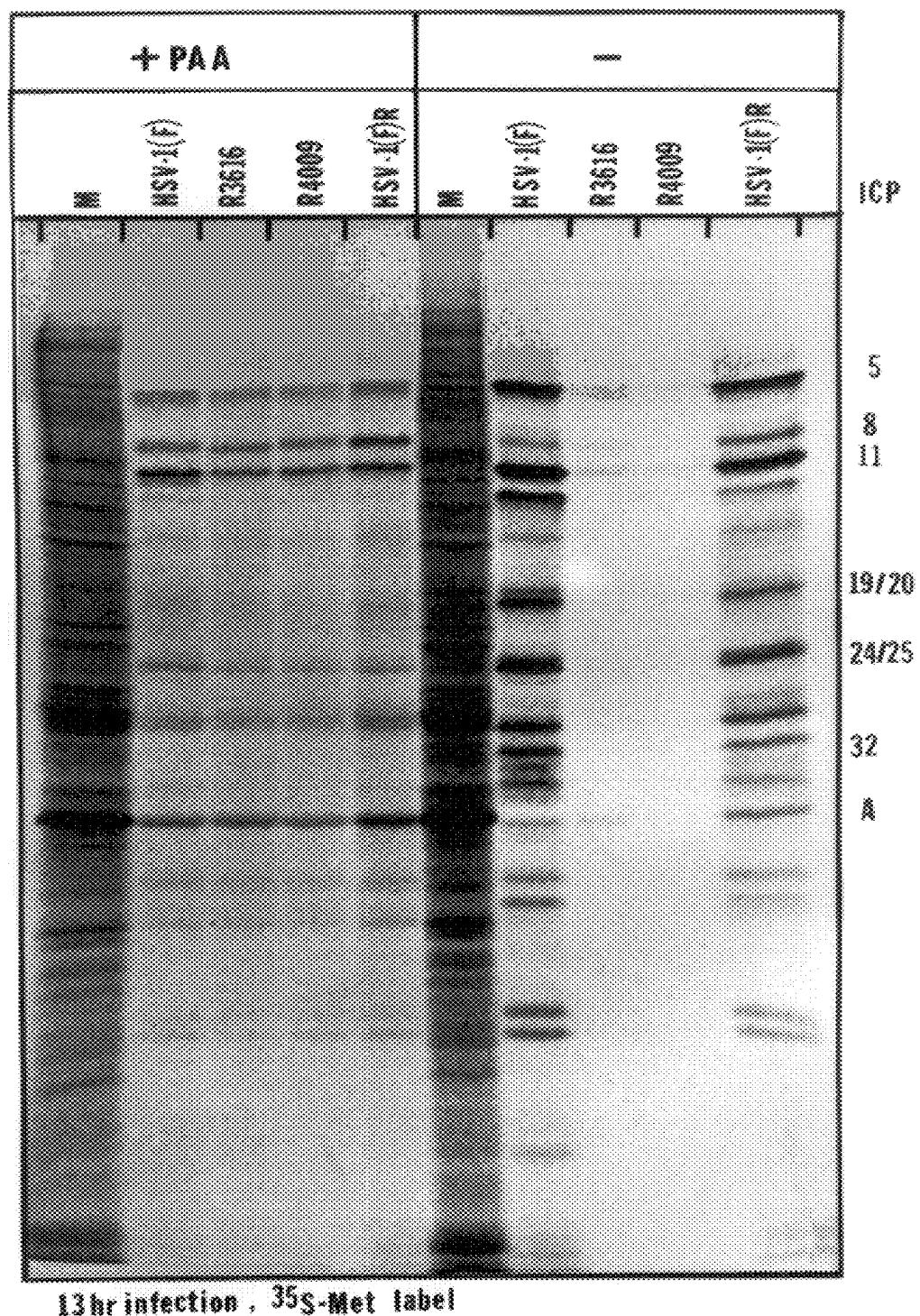
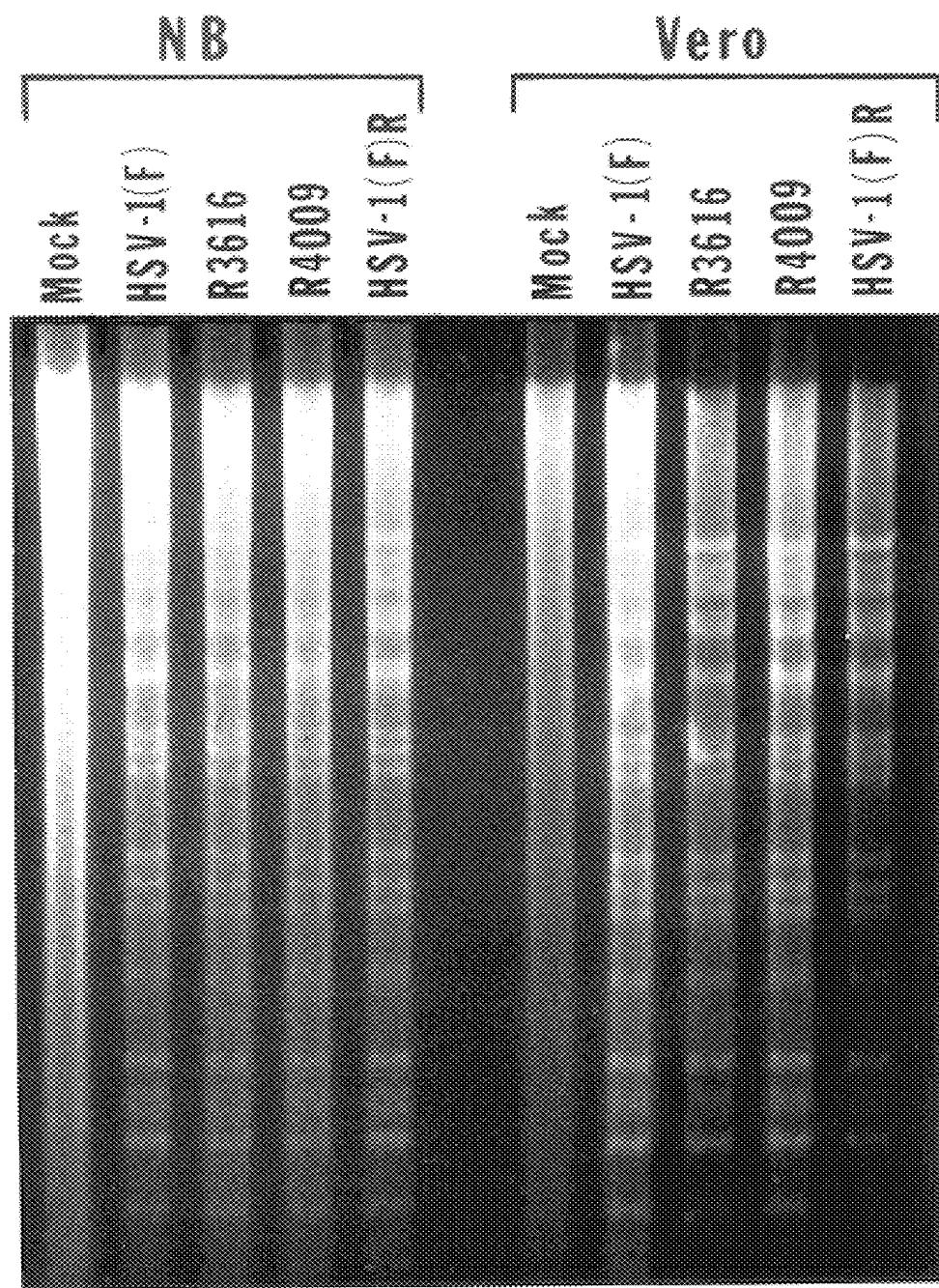
**Fig. 7b**

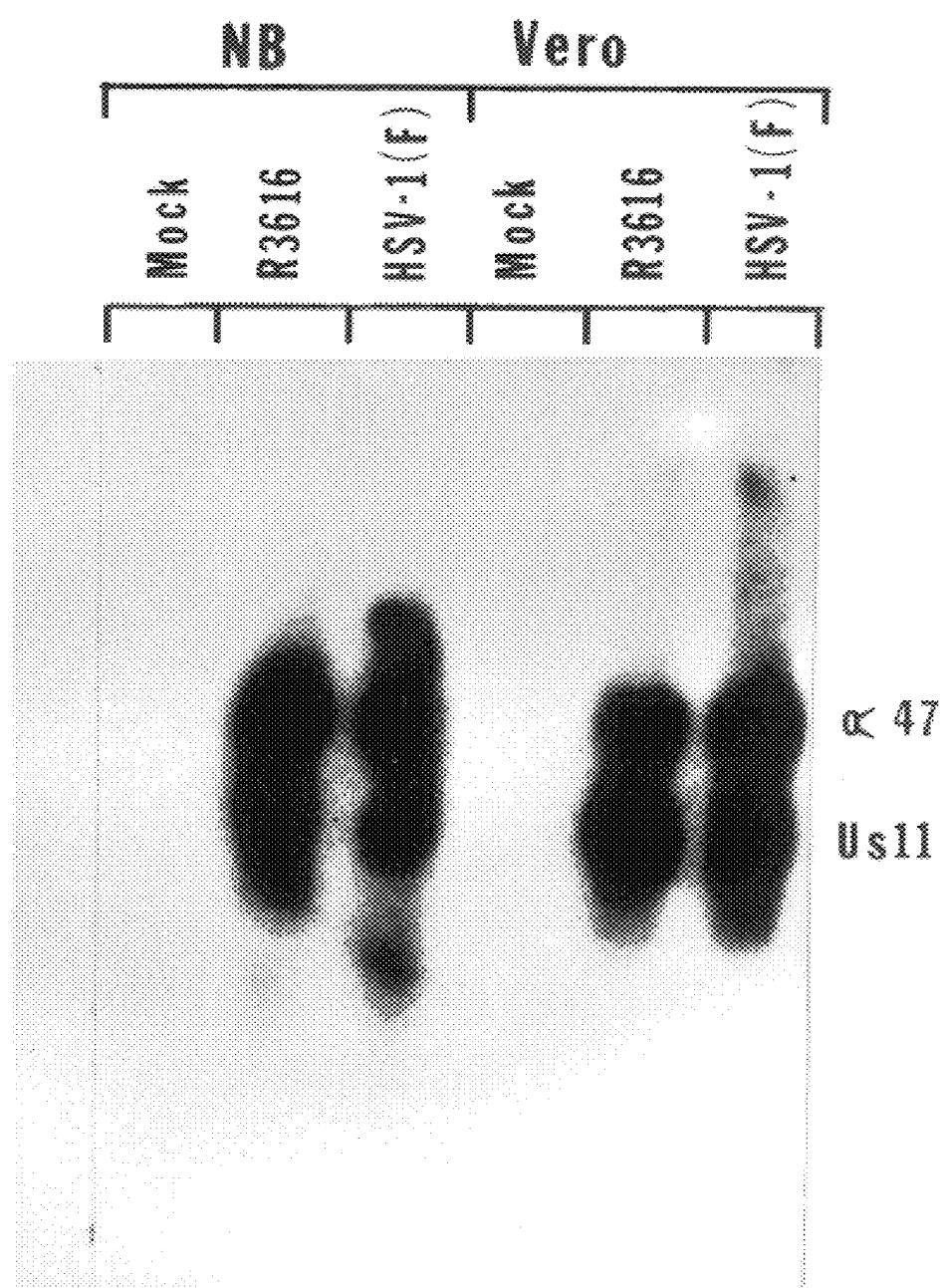
Fig. 7c



**Fig. 8**



**Fig. 9a**

**Fig. 9b**

**METHOD OF SCREENING CANDIDATE  
PROTECTIVE, POTENTIATING, OR  
INHIBITING SUBSTANCES**

**CROSS-REFERENCE TO RELATED  
APPLICATIONS**

This is a division of, commonly assigned application Ser. No. 08/419,853 filed Apr. 11, 1995, now abandoned which is a division of application Ser. No. 07/861,233 filed Mar. 31, 1992, now abandoned.

**BACKGROUND OF THE INVENTION**

The government may own certain rights in the present invention pursuant to grants from the National Cancer Institute (CA47451) and from the National Institute for Allergy and Infectious Diseases (AI24009 and AI1588), and the United States Public Health Service.

**1. Field of the Invention**

The present invention is directed to methods for blocking or delaying programmed cell death, for delivery of gene therapy to specific cells, and for treatment of cancer and other tumorigenic diseases, as well as treatment of viral infections, through the potentiation of programmed cell death in tumor or viral host cells. The present invention is also directed to assays for candidate substances which can either inhibit, or potentiate programmed cell death.

**2. Description of the Related Art**

**a. Programmed Cell Death (Apoptosis)**

In the last decade there has been increasing acceptance in the scientific community of the idea that cells may actually be internally programmed to die at a certain point in their life cycle. As an active cellular mechanism programmed cell death, or apoptosis, has several important implications. First, it is clear that such an active process can provide additional means of regulating cell numbers as well as the biological activities of cells. Secondly, mutations or cellular events which potentiate apoptosis may result in premature cell death. Third, a form of cell death which is dependent on a specific active cellular mechanism can at least potentially be suppressed. Finally, an inhibition of preprogrammed cell death would be expected to lead to aberrant cell survival and could be expected to contribute to oncogenesis.

In general, apoptosis involves distinctive morphological changes including nuclear condensation and degradation of DNA to oligonucleosomal fragments. In certain circumstances it is evident that apoptosis is triggered by or is preceded by changes in protein synthesis. Apoptosis appears to provide a very clean process for cellular destruction, in that the cells are disposed of by specific recognition and phagocytosis prior to bursting. In this manner cells can be removed from a tissue without causing damage to the surrounding cells. Thus, it can be seen that programmed cell death is crucial in a number of physiological processes, including morphological development, clonal selection in the immune system, and normal cell maturation and death in other tissue and organ systems.

It has also been demonstrated that cells can undergo apoptosis in response to environmental information. Examples include the appearance of a stimulus, such as glucocorticoid hormones for immature thymocytes, or the disappearance of a stimulus, such as interleukin-2 withdrawal from mature lymphocytes, or the removal of colony stimulating factors from hemopoietic precursors (for a review of literature see Williams, *Cell*, 85: 1097-1098, Jun. 28, 1991). Furthermore, it has recently been demonstrated that the response of removal to nerve growth factor from

established neuronal cell cultures mimics target removal, or axotomy, or other methods of trophic factor removal, and it has been postulated that the cellular mechanism involved in this response is a triggering of a suicide program or programmed cell death following the nerve growth factor removal. (See Johnson et al., *Neurobiol. of Aging*, 10: 549-552, 1989). The authors propose a "death cascade" or "death program", which envisions that trophic factor deprivation initiates the transcription of new mRNA and the subsequent translation of that mRNA into death associated proteins which act in sequence to ultimately produce "killer proteins". Such an intracellular mechanism seems to fit well with the characteristics of apoptosis discussed above, e.g., death of specific cells without the release of harmful materials and without the disruption of tissue integrity. Furthermore, the authors indicate that inhibitors of macromolecular synthesis prevented the death of neurons in the absence of nerve growth factor.

Studies have been conducted to explore the possibility that tumor cells could be eliminated by artificially triggering apoptosis. The APO-1 monoclonal antibody can induce apoptosis in several transformed human B and T cell lines. The antibody binds to a surface protein and could act either by mimicking a positive death-inducing signal or by blocking the activity of a factor required for survival. Also, anti-FAS antibodies have similar effects, and the recent cloning and sequencing of the gene for the FAS antigen has shown that it is a 63 kilodalton transmembrane receptor. Itoh et al., *Cell* 66: 233-243 (1991).

However, it is important to note that neither APO-1 nor FAS can function exclusively as triggers for cell death. Both are cell surface receptors that may activate quite different responses under other circumstances. Moreover, these antigens are not confined to tumor cells and their effect on normal cells is certainly an important consideration, as is the possible appearance of variants that no longer display the antigens.

It has also been demonstrated that the cell death induced by a range of cytotoxic drugs, including several used in cancer therapy, has also been found to be a form of apoptosis. In fact, the failure of apoptosis in tumor cells could be of fundamental importance in contributing not only to the evasion of physiological controls on cell numbers, but also to resistance both to natural defenses and to clinical therapy.

It has also been demonstrated that expression of the bcl-2 gene can inhibit death by apoptosis. The bcl-2 gene was isolated from the breakpoint of the translocation between chromosomes 14 and 18 found in a high proportion of the most common human lymphomas, that being follicular B cell lymphomas. The translocation brings together the bcl-2 gene and immunoglobulin heavy chain locus, resulting in an aberrantly increased bcl-2 expression in B cells. Subsequently, Henderson et al. (*Cell*, 65: 1107-1115, 1991) demonstrated that expression of latent membrane protein 1 in cells infected by Epstein-Barr virus protected the infected B cells from programmed cell death by inducing expression of the bcl-2 gene. Sentman et al. (*Cell*, 67: 879-88, Nov. 29, 1991) demonstrated that expression of the bcl-2 gene can inhibit multiple forms of apoptosis but not negative selection in thymocytes, and Strasser et al. (*Cell*, 67: 889-899, Nov. 29, 1991) demonstrated that expression of a bcl-2 transgene inhibits T cell death and can perturb thymic selfcensorship. Clem et al. (*Science*, 245: 1388-1390, Nov. 29, 1991) identified a specific baculovirus gene product as being responsible for blocking apoptosis in insect cells.

**b. Herpes Virus Infections and Neurovirulence**

The family of herpes virus includes animal viruses of great clinical interest because they are the causative agents

of many diseases. Epstein-Barr virus has been implicated in B cell lymphoma; cytomegalovirus presents the greatest infectious threat to AIDS patients; and Varicella Zoster Virus, is of great concern in certain parts of the world where chicken pox and shingles are serious health problems. A worldwide increase in the incidence of sexually transmitted herpes simplex (HSV) infection has occurred in the past decade, accompanied by an increase in neonatal herpes. Contact with active ulcerative lesions or asymptotically excreting patients can result in transmission of the infectious agent. Transmission is by exposure to virus at mucosal surfaces and abraded skin, which permit the entry of virus and the initiation of viral replication in cells of the epidermis and dermis. In addition to clinically apparent lesions, latent infections may persist, in particular in sensory nerve cells. Various stimuli may cause reactivation of the HSV infection. Consequently, this is a difficult infection to eradicate. This scourge has largely gone unchecked due to the inadequacies of treatment modalities.

The known herpes viruses appear to share four significant biological properties:

1. All herpes viruses specify a large array of enzymes involved in nucleic acid metabolism (e.g., thymidine kinase, thymidylate synthetase, dUTPase, ribonucleotide reductase, etc.), DNA synthesis (e.g., DNA polymerase helicase, primase), and, possibly, processing of proteins (e.g., protein kinase), although the exact array of enzymes may vary somewhat from one herpesvirus to another.

2. Both the synthesis of viral DNAs and the assembly of capsids occur in the nucleus. In the case of some herpes viruses, it has been claimed that the virus may be de-enveloped and re-enveloped as it transits through the cytoplasm. Irrespective of the merits of these conclusions, envelopment of the capsids as it transits through the nuclear membrane is obligatory.

3. Production of infectious progeny virus is invariably accompanied by the irreversible destruction of the infected cell.

4. All herpes viruses examined to date are able to remain latent in their natural hosts. In cells harboring latent virus, viral genomes take the form of closed circular molecules, and only a small subset of viral genes is expressed.

Herpes viruses also vary greatly in their biologic properties. Some have a wide host-cell range, multiply efficiently, and rapidly destroy the cells that they infect (e.g., HSV-1, HSV-2, etc.). Others (e.g., EBV, HHV6) have a narrow host-cell range. The multiplication of some herpes viruses (e.g., HCMV) appears to be slow. While all herpes viruses remain latent in a specific set of cells, the exact cell in which they remain latent varies from one virus to another. For example, whereas latent HSV is recovered from sensory neurons, latent EBV is recovered from B lymphocytes. Herpes viruses differ with respect to the clinical manifestations of diseases they cause.

Herpes simplex viruses 1 and 2 (HSV-1, HSV-2), are among the most common infectious agents encountered by humans (Corey and Spear, *N. Eng. J. Med.*, 314: 686-691, 1986). These viruses cause a broad spectrum of diseases which range from mild and nuisance infections such as recurrent herpes simplex labialis, to severe and life-threatening diseases such as herpes simplex encephalitis (HSE) of older children and adults, or the disseminated infections of neonates. Clinical outcome of herpes infections is dependent upon early diagnosis and prompt initiation of antiviral therapy. However, despite some successful therapy, dermal and epidermal lesions recur, and HSV infections of neonates and infections of the brain are associated with high

morbidity and mortality. Earlier diagnosis than is currently possible would improve therapeutic success. In addition, improved treatments are desperately needed.

Extrinsic assistance has been provided to infected individuals, in particular, in the form of chemicals. For example, chemical inhibition of herpes viral replication has been effected by a variety of nucleoside analogues such as acyclovir, 5-fluorodeoxyuridine (FUDR), 5-iododeoxyuridine, thymine arabinoside, and the like.

Some protection has been provided in experimental animal models by polyspecific or monospecific anti-HSV antibodies, HSV-primed lymphocytes, and cloned T cells to specific viral antigens (Corey and Spear, *N. Eng. J. Med.*, 314: 686-691, 1986). However, no satisfactory treatment has been found.

The  $\gamma_134.5$  gene of herpes simplex virus maps in the inverted repeat region of the genome flanking the L component of the virus. The discovery and characterization of the gene was reported in several articles (Chou and

Roizman, *J. Virol.*, 57: 629-635, 1986, and *J. Virol.*, 64: 1014-1020, 1990; Ackermann et al., *J. Virol.*, 58: 843-850, 1986). The key features are: (i) the gene encodes a protein of 263 amino acid in length; (ii) the protein contains Ala-Thr-Pro trimer repeat ten times in the middle of the coding sequence; (iii) the protein is basic in nature and consists of large number of Arg and Pro amino acids; (iv) the promoter of the gene maps in the a sequence of the genome which also serves several essential viral functions for the virus; (v) the cis-acting element essential for the expression of the gene  $\gamma_134.5$  is contained within the a sequence, in particular, the DR2 (12 base pair sequence repeated 22 times) and U<sub>b</sub> element. This type of promoter structure is unique to this gene and not shared by other viral gene promoters.

The function of the gene  $\gamma_134.5$  in its ability to enable the virus to replicate, multiply and spread in the central nervous system (CNS) was demonstrated by a set of recombinant viruses and by testing their abilities to cause fatal encephalitis in the mouse brain. The mutant viruses lacking the gene therefore lost their ability to multiply and spread in the CNS and eyes and therefore is non-pathogenic. See Chou et al., *Science*, 250: 1212-1266, 1990.

The  $\gamma_134.5$  gene functions by protecting the nerve cells from total protein synthesis shutoff in a manner characteristic of programmed cell death (apoptosis) in neuronal cells. The promoter appears to contain stress response elements and is transactivated by exposure to UV irradiation, viral infection, and growth factor deprivation. These data suggest that the gene  $\gamma_134.5$  is transactivated in the nerve cells at times of stress to prevent apoptosis.

The significance of these findings therefore lies in the fact that  $\gamma_134.5$  extends viability or lends protection to the nerve cells so that in this instance, the virus can replicate and spread from cell to cell—defined as neurovirulence. It also appears that the protection can be extended to other toxic agents or environmental stresses to which the cell is subjected. An important aspect about the nature of the neurons, unlike any other cells in human, is the fact that neurons in the brain, eyes or CNS do not regenerate which forms the basis of many impaired neurological diseases. Any genes or drugs that extend the life of cells from death or degeneration can be expected to have a significant impact in the area of neural degeneration.

The role of  $\gamma_134.5$ , and anti-apoptosis factors, in infected cells is in its early stages of elucidation. Recent studies have suggested that Epstein-Barr virus enhances the survival capacity of infected cells through latent membrane protein

1(LMP1)-induced up-regulation of bcl-2. In that system it is postulated that LMP 1 induced bcl-2 up regulation gives virus infected B cells the potential to by-pass physiological selection and gain direct access to long lived memory B cell pools. However, bcl-2 expression fails to suppress apoptosis in some situations, for example upon withdrawal of interleukin-2 or interleukin-6. Moreover, the intracellular mechanism of action of bcl-2 expression remains unknown.

c. Programmed Cell Death and Disease Therapy

In light of the foregoing, it is apparent that the expression of  $\gamma_1$ 34.5 in CNS cells added an extra dimension of protection to the neurons against viral infection, and naturally occurring and stress-induced apoptosis. An appreciation of this extra dimension of protection can be utilized in novel and innovative means for control and treatment of central nervous system (CNS) disorders. Specifically, treatment of CNS degenerative diseases, including Alzheimer's disease, Parkinson's disease, Lou Gerig's disease, and others the etiology of which may be traceable to a form of apoptosis, and the treatment of which is currently very poor, could be improved significantly through the use of either the  $\gamma_1$ 134.5 gene in gene therapy or the protein expressed by  $\gamma_1$ 34.5 as a therapeutic agent. This is especially critical where the death of neuronal cells is involved, due to the fact that, as noted, such cells do not reproduce post-mitotically. Since a finite number of neurons are available it is crucial to have available methods and agents for their protection and maintenance.  $\gamma_1$ 134.5 is also a very useful gene for assays of substances which mimic the effect of  $\gamma_1$ 34.5 and block stress of biologically induced programmed cell death.

Furthermore, the HSV-1 virus, appropriately modified so as to be made non-pathogenic, can serve as a vehicle for delivery of gene therapy to neurons. The HSV-1 virus is present in neurons of the sensory ganglia of 90% of the world's human population. The virus ascends into neuronal cell bodies via retrograde axonal transport, reaching the axon from the site of infection by the process of neurotropism. Once in the neuronal cell body the virus remains dormant until some form of stress induces viral replication (e.g. UV exposure, infection by a second virus, surgery or axotomy). As noted, the use of HSV-1 as a vector would necessitate construction of deletion mutants to serve as safe, non-pathogenic vectors. Such a virus would act as an excellent vector for neuronal gene therapy and its use would be an especially important development since few methods of gene therapy provide a means for delivery of a gene across the central nervous system's blood-brain barrier.

Moreover, other viruses, such as HSV-2, picornavirus, coronavirus, eunyavirus, togavirus, rhabdovirus, retrovirus or vaccinia virus, are available as vectors for  $\gamma_1$ 34.5 gene therapy. As discussed with regard to the use of HSV-1 viruses, these vectors would also be altered in such a way as to render them non-pathogenic. In addition to the use of an appropriately mutated virus, implantation of transfected multipotent neural cell lines may also provide a means for delivery of the  $\gamma_1$ 134.5 gene to the CNS which avoids the blood brain barrier.

In addition, use of the HSV-1 virus with a specific mutation in the  $\gamma_1$ 34.5 gene provides a method of therapeutic treatment of tumorogenic diseases both in the CNS and in all other parts of the body. The " $\gamma_1$ 34.5 minus" virus can induce apoptosis and thereby cause the death of the host cell, but this virus cannot replicate and spread. Therefore, given the ability to target tumors within the CNS, the  $\gamma_1$ 34.5 minus virus has proven a powerful therapeutic agent for hitherto virtually untreatable forms of CNS cancer. Furthermore, use of substances, other than a virus, which inhibit or block

expression of genes with antiapoptotic effects in target tumor cells can also serve as a significant development in tumor therapy and in the treatment of herpes virus infection, as well as treatment of infection by other viruses whose neurovirulence is dependent upon an interference with the host cells' programmed cell death mechanisms.

## SUMMARY OF THE INVENTION

This invention relates to methods for the prevention or treatment of programmed cell death, or apoptosis, in neuronal cells for therapy in connection with neurodegenerative diseases, as well as methods of treatment of cancer and other tumorogenic diseases and herpes virus infection. The present invention also relates to assay methodologies allowing for the identification of substances capable of modulating the effects of the  $\gamma_1$ 34.5 gene or its protein expression product ICP34.5, i.e., substances capable of potentiating or inhibiting their effects. Additionally, the present invention also relates to assay methodologies designed to identify candidate substances able to mimic either  $\gamma_1$ 34.5 expression or the activity of ICP34.5. The present invention also relates to methods of delivering genes to cells for gene therapy.

In one illustrative embodiment of the present invention a method of preventing or treating programmed cell death in neuronal cells is described in which a non-pathogenic vector is prepared which contains the  $\gamma_1$ 34.5 gene. This vector is then introduced into neuronal cells which are presently undergoing or are likely to undergo programmed cell death. Those skilled in the art will realize that several vectors are suitable for use in this method, although the present invention envisions the use of certain unique and novel vectors designed specifically for use in connection with delivery of the  $\gamma_1$ 34.5 gene.

One such vector envisioned by the present invention is the HSV-1 virus itself, modified so as to render it non-pathogenic. Because of the unique capability of the HSV-1 virus to use an axon's internal transport system to move from the peripheral nerve endings of the neuron into the neuronal cell body, the present invention proposes the use of the non-pathogenic HSV-1 virus injected into the vicinity of the synaptic terminals of affected neurons, or in the area of a peripheral wound or lesion or other appropriate peripheral locus. The HSV-1 virus containing the  $\gamma_1$ 34.5 gene, under a different target-specific promoter, would then be transported into the neuronal cell body via retrograde axonal transport.

The present invention envisions specific genomic modifications being introduced into the HSV-1 virus in order to render the virus non-cytotoxic. These modifications could include deletions from the genome, rearrangements of specific genomic sequences, or other specific mutations. One example of such a modification comprises modification or deletion of the  $\alpha 4$  gene which encodes the ICP4 protein. Deletion or modification of the gene expressing ICP4 renders the HSV-1 virus unable to express genes required for viral DNA and structural protein synthesis. However, the  $\gamma_1$ 34.5 gene placed under a suitable promoter would be expressed, thus inducing an anti-apoptotic effect in the neuron without the potential for stress induced neurovirulence. Other genes which might be modified include the  $\alpha 0$  gene. The present invention also envisions the use of other vectors including, for example, retrovirus, picorna virus, vaccinia virus, HSV-2, coronavirus, eunyavirus, togavirus or rhabdovirus vectors. Again, use of such viruses as vectors will necessitate construction of deletion mutations so that the vectors will be safe and non-pathogenic.

Another method by which the present invention envisions introducing the  $\gamma_1$ 34.5 gene into neuronal cells undergoing or likely to undergo programmed cell death, is through the use of multi-potent neural cell lines. Such lines have been shown to change phenotype in vitro and have also been demonstrated to become integrated into the central nervous system of mice and to differentiate into neurons or glia in a manner appropriate to their site of engraftment. Snyder, et al., *Cell*, 68: 33-51, 1992. Transplant or engraftment of multi-potent neural cell lines into which the  $\gamma_1$ 34.5 gene has been introduced into an area of the central nervous system in which cells are undergoing or are likely to undergo programmed cells death is expected to lead to reversal and inhibition of programmed cell death.

It is expected that the ability of  $\gamma_1$ 34.5 to inhibit apoptosis will be a boon not only in human medicine, but also in basic scientific research. In this regard the present invention also envisions the use of the  $\gamma_1$ 34.5 gene in the extension of the life of neuronal cells in cell culture. Introduction of a non-cytotoxic vector into cultured neuronal cells will have an anti-apoptotic effect and will thereby extend the life of cell cultures. This in turn will extend the time periods over which experimentation may be conducted, and can also be expected to decrease the cost of conducting basic research.

In addition to utilizing a vector comprising the  $\gamma_1$ 34.5 gene, the present invention also discloses a method of preventing or treating programmed cell death in neuronal cells which involves the use of the product of expression of the  $\gamma_1$ 34.5 gene. The protein expressed by  $\gamma_1$ 34.5 is called ICP34.5. Ackermann, et al. (*J. Virol.*, 58: 843-850, 1986) reported that ICP34.5 has an apparent molecular weight of 43,500 upon SDS-polyacrylamide gel electrophoresis, appears to accumulate largely in the cytoplasm of HIV infected cells, and in contrast to many HSV-1 proteins, ICP34.5 has been demonstrated to be soluble in physiologic solutions.

In practicing this method or the method in which the  $\gamma_1$ 34.5 gene is introduced into cells, it is envisioned that the  $\gamma_1$ 34.5 gene or a biological functional equivalent thereof could be used for gene therapy, or ICP34.5 in a purified form or a biological functional equivalent of the ICP34.5 protein could be utilized as an anti-apoptotic agent. As used herein, functional equivalents are intended to refer to those proteins, and their encoding nucleic acid sequences, in which certain structural changes have been made but which nonetheless are, or encode, proteins evidencing an effect similar to that of ICP34.5.

In light of the fact that certain amino acids may be substituted for other amino acids in a protein without appreciable loss of defined functional activity, it is contemplated by the inventors that various changes may be made in the sequence of the ICP34.5 protein (or the underlying DNA of the  $\gamma_1$ 34.5 gene) without an appreciable loss of biological utility or activity. Amino acids with similar hydrophobicity scores may be substituted for one another (see Kyte et al., *J. Mol. Biol.*, 157: 105-132, 1982, incorporated herein by reference), as may amino acids with similar hydrophilicity values, as described in U.S. Pat. No. 4,554,101, incorporated herein by reference.

Therefore, amino acid substitutions are generally based on the relative similarity of the amino acid side-chain substituents, for example, their hydrophobicity, hydrophilicity, charge, size, and the like. Exemplary substitutions which take various of the foregoing characteristics into consideration are well known to those of skill in the art and include: arginine and lysine; glutamate and aspartate;

serine and threonine; glutamine and asparagine; and valine, leucine and isoleucine.

This embodiment of the present invention describes a method which involves combining ICP34.5 or a biological functional equivalent thereof with a pharmaceutically acceptable carrier in order to form a pharmaceutical composition. (It should be understood in subsequent discussions that when  $\gamma_1$ 34.5 or ICP34.5 are referred to, the inventors intend to include biological functional equivalents, including any chemicals which mimic the effect of  $\gamma_1$ 34.5.) Such a composition would then be administered to neurons likely to undergo or undergoing programmed cell death. Such a composition could be administered to an animal using intravenous, intraspinal injection or, in certain circumstances, oral, intracerebral or intraventricular administration may be appropriate. Furthermore, neuronal cells in culture could also benefit from administration of ICP34.5 through administration directly into the medium in which the neuronal cells are grown.

ICP34.5 can be prepared using a nucleic acid segment which is capable of encoding ICP34.5 (i.e., the  $\gamma_1$ 34.5 gene or a biological functional equivalent). Such a segment could be expressed using, for example, a technique involving transferring the  $\gamma_1$ 34.5 segment into a host cell, culturing the host cell under conditions suitable for expression of the segment, allowing expression to occur, and thereafter isolating and purifying the protein using well established protein purification techniques. The nucleic acid segment would be transferred into host cells by transfection or by transformation of a recombinant vector into the host cell.

A particularly important embodiment of the present invention relates to assays for candidate substances which can either mimic the effects of the  $\gamma_1$ 34.5 gene, or mimic the effects of ICP34.5, as well as assays for candidate substances able to potentiate the function of  $\gamma_1$ 34.5 or potentiate the protective function of ICP34.5. Additionally, methods for assaying for candidate substances able to inhibit either  $\gamma_1$ 34.5 expression or the activity of ICP34.5 are also embodiments of the present invention.

In an exemplary embodiment, an assay testing for candidate substances which would block the expression of the anti-apoptosis gene or inhibit the activity of an anti-apoptotic protein such as ICP34.5 would proceed along the following lines. A test plasmid construct bearing the a sequence promoter and portions of the coding sequence of  $\gamma_1$ 34.5 is fused to the lacZ reporter gene, or any other readily assayable reporter gene. This construct is then introduced into an appropriate cell line, for example a neuroblastoma or PC12 cell line, by G418 selection. A clonal and continuous cell line for screening purposes is then established. A control plasma construct bearing an HSV late promoter (a promoter which would normally not be expressed in cell lines and not induced to express by a stress factor which would normally induce apoptosis) is fused to the same or different indicator gene. This construct is also introduced into a continuous clonal cell line and serves as a control for the test cell line. The anti-apoptosis drugs would then be applied. Environmental stresses which typically trigger a sequence promoter activation and cause programmed cell death, such as UV injury, viral infection or deprivation of nerve growth factor, would then be applied to the cells. In control cells, the stress should have no effect on the cells and produce no detectable reaction in the assay. Stress in a test cell line in the absence of a positive candidate substance would give rise to an appropriate reaction, typically a colorimetric reaction. Introduction of stress to the test cell line in the presence of the candidate substance would give rise to an opposite calori-

metric reaction indicating that the candidate substance interferes either with expression of the  $\gamma_134.5$  gene, or with the ability of the substance to interfere with the anti-apoptotic activity of ICP34.5.

Similarly, the present invention describes an assay for candidate substances which would mimic or potentiate the activity of ICP34.5, or which would mimic the expression of  $\gamma_134.5$ , and such an assay would proceed along lines similar to those described above. A test cell line (e.g., a neuroblastoma cell line) constitutively expressing ICP34.5 and a fluorescent tagged cellular gene or any other tag providing an easily detected marker signalling viability of the cells is produced. In addition, a corresponding null cell line consisting of an appropriate indicator gene, for example the a-lacZ indicator gene, and the same host indicator gene as in the test cell line is also produced. Also, a third cell line (e.g., a vero cell line) consisting of the same indicator gene and the identical host indicator gene is also produced. Again, environmental stresses which trigger programmed cell death in the absence of  $\gamma_134.5$  are applied to the cells. Candidate substances are also applied in order to determine whether they are able to mimic or potentiate the anti-apoptotic effects of  $\gamma_134.5$  expression or the anti-apoptotic activity of ICP34.5 or biological functional equivalents thereof.

The present invention also embodies a method of delivering genes for gene therapy. In an exemplary embodiment, the method involves combining the gene used for gene therapy with a mutated virus such as those described above, or with the HSV-1 virus rendered non-pathogenic. The gene and the virus are then combined with a pharmacologically acceptable carrier in order to form a pharmaceutical composition. This pharmaceutical composition is then administered in such a way that the mutated virus containing the gene for therapy, or the HSV-1 wild type virus containing the gene, can be incorporated into cells at an appropriate area. For example, when using the HSV-1 virus, the composition could be administered in an area where synaptic terminals are located so that the virus can be taken up into the terminals and transported in a retrograde manner up the axon into the axonal cell bodies via retrograde axonal transport. Clearly, such a method would only be appropriate when cells in the peripheral or central nervous system were the target of the gene therapy.

The present invention also envisions methods and compositions for the treatment of cancer and other tumorogenic diseases, as well as herpes infections or other infections involving viruses whose virulence is dependent upon an anti-apoptotic effect. Candidate substances identified as having an inhibiting effect upon either the expression or activity of ICP34.5 identified in the assay methods discussed above could be used to induce cell death in target tumor cells, or in virus-infected cells. Pharmaceutical compositions containing such substances can be introduced using intrathecal, intravenous, or direct injection into the tumor or the infected area, as appropriate.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 sets forth the relationship between FIGS. 1a-1d and how these figures should be compiled and viewed for a proper understanding of their content.

FIGS. 1a-1d show DNA sequence comparisons of HSV-1 strains F, 17syn+, MGH-10, and CVG-2 in the region of the gene for ICP34.5 (FIGS. 1a and 1b) and the predicted open frames for ICP34.5 in these strains (FIGS. 1c and 1d). Unless otherwise indicated by a new base (insertion of A, C, G, or T), a new amino acid (three-letter code), or absence of

a base or amino acid (-), the sequences for strains HSV-1 (17)syn+, HSV-1(MGH-10), and HSV-1(CVG-2) were identical to the sequence for HSV-1(F). An asterisk indicates initiation of a repeat sequence of nine nucleotides or three amino acids. Direct repeat 1(DR1) designates the 20-base-pair repeat sequence flanking the a sequence. Sequences upstream of direct repeat 1 are contained within the a sequence. The number at the end of each line indicates the relative position from nucleotide 1 (FIGS. 1a and 1b) or amino acid 1 (FIGS. 1c and 1d). The initiation and termination codons for the HSV-1(F) sequence are underlined.

FIG. 2 shows sequence arrangements of the genome of wild-type strain HSV-1 strain F [HSV-1(F)] and of recombinant viruses derived from it. Top line, the sequence arrangement of HSV-1(F)  $\Delta 305$ . The rectangles identify the inverted repeats ab, b' a' c, and ca. The HSV-(F) a sequence is present in a direct orientation at the two genomic termini and in the inverted orientation at the junction between the long and short components. The b and c sequences are approximately 9 and 6 kbp long, respectively. The triangle marked TK identifies the position of the tk gene and of the Bg1 II to Sac I sequence of BamHI Q fragment deleted from HSV-1(F) $\Delta 305$ . Lines two and three from the top show that the b sequences contain the genes specifying ICP34.5 and ICPO and, since b sequence is repeated in an inverted orientation, there are two copies of these genes per genome. The construction of the a24-tk fragment containing portions of the glycoprotein H gene has been described. Chou and Roizman, *J. Virol.*, 57: (1986); Ackerman et al., *J. Virol.*, 58: 843 (1986); Chou and Roizman, *J. Virol.*, 64: 1014 (1990). Line 7 shows a schematic diagram of the insertion of the oligonucleotide containing stop codons in all three reading frames. The plasmids pRB3615 and pRB2976 used in the construction of R4002 and R4004, respectively, were described elsewhere. Chou and Roizman, *J. Virol.*, 57: 629 (1986) and *J. Virol.*, 64: 1014 (1990). To generate pRB3616, plasmid pRB143 was digested with BstEII and Stu I, blunt-ended with T4 polymerase, and religated. The asterisks designate nucleotides from vector plasmid that form cohesive ends with the synthesized oligomers. The insertion of the  $\alpha 4$  epitope into the first amino acid of ICP34.5 (line 9) has been described, Chou and Roizman, *J. Virol.*, 64: 1014 (1990), except that in this instance the sequence was inserted into both copies of the  $\gamma_134.5$  gene. The tk gene was restored in all recombinant viruses tested in mice. HSV-1(F)R (line 6) was derived from R3617 by restoration of the sequences deleted in  $\gamma_134.5$  and tk genes. N, Be, S, and St are abbreviations for Neo I, BstEII, Sac I, and Stu I restriction endonucleases (New England Biolabs), respectively. The numbers in parentheses are the tk<sup>+</sup> version of each construct tested in mice.

FIGS. 3a and 3b show an autoradiographic image of electrophoretically separated digest of plasmid, wild-type, and mutant virus DNAs, transferred to a solid substrate and hybridized with labelled probes for the presence of  $\gamma_134.5$  and tk genes. The plasmids or viral DNAs shown were digested with BamHI or, in the case of R4009 shown in lanes 10, with both BamHI and Spe I. The hybridization probes were the fragment Nco I to Sph I contained entirely within the coding sequences of  $\gamma_134.5$  (FIG. 3a) and the BamHI Q fragment of HSV-1(F) (FIG. 3b). The probes were labeled by nick translation of the entire plasmid DNAs with [ $\alpha$ -<sup>32</sup>P] deoxycytidine triphosphate and reagents provided in a kit (Du Pont Biotechnology Systems). The DNAs that were limit digested with BamHI (all lanes) or both BamHI and Spe I (left panel, lane 10) were electrophoretically separated on 0.8% agarose gels in 90 mM trisphosphate buffer at 40 V

overnight. The DNA was then transferred by gravity to two nitrocellulose sheets sandwiching the gel and hybridized overnight with the respective probes.  $\gamma_{134.5}$  maps in BamHI S and SP fragments, which form a characteristic ladder of bands at 500-bp increments. The ladders are a consequence of a variable number of sequences in the repeats flanking the unique sequences of the junction between the long and short components, whereas BamHI S is the terminal fragment of the viral genome at the terminus of the long component, whereas BamHI SP is a fragment formed by the fusion of the terminal BamHI S fragment with BamHI P, the terminal BamHI fragment of the short component. Bands of BamHI S, SP, and Q and their deleted versions, ABamHI S, ABamHI SP, and ABamHI Q (AQ), respectively, are indicated. Band 1 represents the 1.7-kbp  $\alpha27$ -tk insert into the BamHI SP fragment in R4002, and therefore this fragment reacted with both labeled probes (lanes 4). Band 2 represents the same insertion into the BamHI S fragment.

FIGS. 4a and 4b show autoradiographic images (FIG. 4a) and photograph of lysates of cells mock infected (M) or infected with HSV-1(F) and recombinant viruses (FIG. 4b) separated electrophoretically in denaturing polyacrylamide (10%) gels, transferred electrically to a nitrocellulose sheet, and stained with rabbit polyclonal antibody R4 described elsewhere. Ackerman et al., *J. Virol.*, 58: 843 (1986); Chou and Roizman, *J. Virol.*, 64: 1014 (1990). Replicate cultures of Vero cells were infected and labeled with [ $^{35}$ S]methionine (Du Pont Biotechnology Systems) from 12 to 24 hours after infection, and equivalent amounts of cell lysates were loaded in each slot. The procedures were as described (Ackerman et al.; Chou and Roizman) except that the bound antibody was made apparent with the alkaline phosphatase substrate system supplied by Promega, Inc. Infected cell proteins were designated by number according to Honess and Roizman (*J. Virol.*, 12: 1346 (1973)). The chimeric ICP34.5 specified by R4003 migrated more slowly than the protein produced by other viruses because of the increased molecular weight caused by the insertion of the epitope.

FIG. 5 is a schematic representation of the genome structure and sequence arrangements of the HSV-1 strain F [HSV01(F)] and related mutants. Top line: The two covalently linked components of HSV-1 DNA, L and S, each consist of unique sequences flanked by inverted repeats (7, 31). The reiterated sequences flanking the L component designated as ab ad b'a' are each 9 kb in size, whereas the repeats flanking the S component are 6.3 kb in size (31). Line 2: expansion of portions of the inverted repeat sequences ab and b'a' containing the  $\gamma_{134.5}$  and  $\alpha0$  genes. Line 3: sequence arrangement and restriction endonuclease sites in the expanded portions shown in line 2. Open box represents the 20 bp direct repeat sequence (DR1), flanking the a sequence (26,27). Restriction site designations are N,-NcoI; Be,-BstEII; S,SacI; St,-StuI. Line 4: the thin line and filled rectangle represent the transcribed and coding domains of the  $\gamma_{134.5}$  gene (406). Vertical line, location of the transcription initiation sites of  $\gamma_{134.5}$  and of  $\alpha0$  genes. In the R3616 viral recombinant, one Kb was deleted between BstEII at 28th amino acid of  $\gamma_{134.5}$  to StuI at the 3' terminus of the genes as shown. In HSV-1(F)R DNA, the sequences deleted from the  $\gamma_{134.5}$  gene in R3616 were restored and therefore the virus could be expected to exhibit a wild-type phenotype. The R4009 recombinant virus DNA contains an in frame translation termination codons at the BstEII site. Vertical arrow on top points to the site of the stop codon insertion.

FIGS. 6a and 6b shows an autoradiographic image of electrophoretically separated lysates of infected cells labeled

for 90 minutes with [ $^{35}$ S]-methionine at stated time points. The SK-N-SH neuroblastoma and Vero cell lines were mock infected (M) or exposed at 37° C. to 5 pfu of wild-type or mutant viruses in 6 well (Costar, Cambridge, Mass.) dishes. At 2 hours post exposure, the cells were overlaid with mixture 199 supplemented with 1% calf serum. At 5.5 and 11.5 hours post exposure of cells to viruses, replicate infected 6 well cultures were overlaid with 1 ml of the 199 medium lacking unlabeled methionine but supplemented with 50  $\mu$ Ci of [ $^{35}$ S]-methionine (specific activity >1,000 Ci/mmol, Amersham Co. Downers Grove, Ill.). After 90 minutes in labeling medium, the cells were harvested, solubilized in a buffer containing sodium dodecyl sulphate, subjected to electrophoresis on a denaturing 12% polyacrylamide gels crosslinked with N, N' Diallyltartardiamide, electrically transferred to nitrocellulose sheet and subjected to autoradiography as previously described (13). Infected cell polypeptides (ICP) were designated according to Honess and Roizman, *J. Virol.*, 12: 1347-1365 (1973).

FIGS. 7a and 7c show autoradiographic images of labeled polypeptides electrophoretically separated in denaturing gels and photographs of protein bands made apparent by their reactivity with antibodies. The SK-N-SH neuroblastoma and Vero cells were either mock infected (M) or infected with 5 pfu of either R3616 or the parent HSV-1(F) per cell as described in the legend to FIGS. 6a and 6b. The cultures were labeled for 1.5 hr before harvesting at 13th hr post exposure of cells to virus. Preparation of cell extracts, electrophoresis of the polypeptides, electric transfer of the separated polypeptides to a nitrocellulose sheet, and autoradiography were carried out as described elsewhere (Ackerman et al., *J. Virol.*, 52: 108-118, 1984). The nitrocellulose sheets were reacted with the respective antibodies with the aid of kits from Promega, Inc. (Madison, Wis.) according to manufacturer's instruction. Monoclonal antibodies H1142 against  $\alpha27$  and H725 against the product of the U<sub>L</sub>26.5 gene were the generous gift of Lenore Pereira, University of California at San Francisco. The M28 monoclonal antibody to U<sub>S</sub>11 protein and the rabbit polyclonal antibody R161 against viral thymidine kinase ( $\beta$ tk) were made to a specific peptide (M. Sarmiento and B. Roizman, unpublished studies) in this laboratory. ICP designations were the same as noted before.

FIG. 8 shows an autoradiographic image of viral proteins expressed during infection on SK-N-SH neuroblastoma cell lines in the presence or absence of phosphonoacetate (PAA). Duplicate SK-N-SH neuroblastoma cell cultures were either treated with phosphonoacetate (300  $\mu$ g/ml; Sigma Chemical Co., St. Louis, Mo.) starting at 1.5 hr prior to infection continuously until the termination of infection or left untreated. The cultures were either mock infected or exposed to 5 pfu of either HSV-1(F), R3616, R4009 and HSV-1(F)R at 5 pfu/cell. At 11.5 hours post exposure to virus, the cells were overlaid with medium containing 50  $\mu$ Ci of [ $^{35}$ S]-methionine as described in legend to FIG. 6. Polypeptide extraction, electrophoresis on 12% polyacrylamide gels crosslinked with N,N' Diallyltartardiamide, electrical transfer to nitrocellulose sheets and autoradiography were as described in the legend to FIGS. 6a and 6b.

FIGS. 9a and 9b show viral DNA and RNA accumulation in infected SK-N-SH neuroblastoma and Vero cell cultures. FIG. 9a: Photograph of ethidium bromide stained agarose gel containing electrophoretically separated BamHI digests of total DNAs extracted from mock-infected cells or cells infected with HSV-1(F), R3616, R4009 or HSV-1(F)R viruses. FIG. 9b: Hybridization of electrophoretically separated RNA transferred to a nitrocellulose sheets probed with

RNA sequences antisense to  $\alpha 47$ ,  $U_s 10$  and  $U_s 11$  open reading frames. SK-N-SH neuroblastoma and Vero cells were either mock-infected or exposed to 5 pfu of HSV1(F) or of R3616 per cell. Total DNAs were extracted from cells at 17 hr post infection by the procedure published by Katz et al., (*J. Virol.*, 64: 4288–4295), digested with BamHI, electrophoresed in 0.8% agarose gel at 40V overnight and stained with ethidium bromide for visualization. For RNA analysis, SK-N-SH neuroblastoma and Vero cells were either mock-infected or infected with R3616 and HSV-1(F) as described above. At 13 hrs post exposure of cells to virus the RNA was extracted by the procedure of Peppel and Baglioni (*BioTechniques*, 9: 711–712, 1990). The RNAs were then separated by electrophoresis on 1.2% agarose gel, transferred by gravity to a nitrocellulose sheet and probed with anti-sense RNA made from in vitro transcription of pRB3910 off T7 promoter using kit from Promega, Inc. according to manufacturer's instruction.  $\alpha 47$ ,  $U_s 10$  and  $U_s 11$  transcripts overlap in sequence and share the same 3' co-terminal sequence. McGeoch et al., (*J. Gen. Virol.*, 64: 1531–1574 (1988). The  $U_s 10$  transcript is of low abundance and not detected in this assay.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

##### Introduction

The present invention relates to the use of the HSV-1  $\gamma_1 34.5$  gene, the ICP34.5 protein expressed by that gene, and derivatives of the protein which function in a similar manner as therapeutics for (neuronal) programmed cell death. The present invention also relates to the use of altered, non-pathogenic HSV-1 virus (as well as other viruses) as a vector for gene therapy. Other aspects of the present invention relate to assays for detecting candidate substances capable of acting as anti-apoptotic agents, as well as assays for detecting candidate substances able to induce programmed cell death in tumor cells. Additionally, the present invention also relates to methods for treating cancer and other tumorigenic diseases. Finally, the present invention also relates to the use of candidate substances capable of inactivating the  $\gamma_1 34.5$  gene or ICP34.5 and thereby suppressing HSV-1 and other viral infections.

The wild-type HSV-1 genome (150 kilobase pairs) has two components, L and S, each possessing unique sequences flanked by inverted repeats. The repeat sequences of the L component, designated ab and b'a', are each 9 kilobase pairs, whereas the repeat sequences of the S component, designated a'c' and ca, are each 6.5 kilobase pairs. Wadsworth et al., (*J. Virol.*, 15: 1487–1497 (1975). The shared a sequence, 500-base pairs long in HSV1 strain F [HSV-1(F)], is present in one copy at the S component terminus and in one to several copies, in the same orientation, at the junction between L and S components. The L and S components invert relative to each other such that the DNA extracted from virions or infected cells consists of four isomers differing solely in the orientation of the L and S components relative to each other. Hayward et al., (*Proc. Natl. Acad. Sci. USA*, 72: 4243–4247 (1975). The a sequence appears to be a cis-acting site for inversions inasmuch as insertion of the a sequence elsewhere in the genome or deletion of the entire internal inverted repeat sequences (b'a'c') leads to additional inversions or the loss of the ability of the L and S components to invert, respectively. The a sequence was also shown to contain the cis-acting sites for the circularization of the genome after infection, for cleavage of the HSV genome from concatemers, and for encapsidation of the DNA.

HSV-1 genomes contain at least 73 genes whose expression is coordinately regulated and sequentially ordered in cascade fashion. The a genes are expressed first, followed by  $\beta$ ,  $\gamma_1$  and  $\gamma_2$  genes. The differentiation among  $\beta$ ,  $\gamma_1$  and  $\gamma_2$  genes is operationally based on the effect of inhibitors of viral DNA synthesis. Whereas the expression of  $\beta$  genes is stimulated and that of  $\gamma_1$  genes is only slightly reduced by inhibitors of viral DNA synthesis, the expression of  $\gamma_2$  genes stringently requires viral DNA synthesis.

In the course of studies on the function of the a sequence, Chou and Roizman (*Cell*, 41: 803–811, 1985) noted that the chimeric structure consisting of the a sequence fused to the 5' transcribed, noncoding sequences of the thymidine kinase (TK) gene of HSV-1 was inducible in transferred cells and regulated as a  $\gamma_1$  gene when inserted into the viral genome. This observation suggested that the terminus of the a sequence nearest the b sequence of the inverted repeats contained a promoter and the transcription initiation site of a gene whose structural sequences were located in the b sequences flanking the L component. Studies involving hybridization of labeled DNA probes to electrophoretically separated RNAs extracted from infected cells, and S1 nuclease analyses confirmed the existence of RNA transcripts initiating in the a sequence. Nucleotide sequence analyses revealed the presence of an open reading frame capable of encoding a protein 263 amino acids long. Chou and Roizman, (*J. Virol.*, 64: 1014–1020 (1990).

Previous studies have shown that each inverted repeat of the S component contains in its entirety a gene designated  $\alpha 4$ , whereas each of those of the L component contains in its entirety a gene designated  $\alpha 0$ . See, e.g., Mackem and Roizman, (*J. Virol.*, 44: 934–947 (1982). The putative gene identified on the basis of nucleotide sequence and analyses of RNA is also present in two copies per genome. Because of the overlap of the domain of this gene with the a sequence containing the cis-acting sites for inversion, cleavage of DNA from concatemers, and packaging of the DNA, it was of interest to identify and characterize the gene product. For this purpose, the observation that the nucleotide sequence predicted the presence in the protein of the amino acid triplet Ala-Thr-Pro repeated 10 times was utilized, and antibody to a synthetic peptide synthesized on the basis of this sequence reacted with a 43,500-apparent-molecular-weight HSV-1 protein. Ackerman et al., (*J. Virol.*, 58: 843–850, 1986.

The extent of variability of the open reading frame that encodes ICP34.5 was established by comparing the nucleotide sequences of three HSV-1 strains passaged a limited number of times outside a human host. Chou and Roizman (*J. Virol.*, 64: 1014–1020, 1990) reported that the gene that specifies ICP34.5 contains 263 codons conserved in all three limited passage strains but not in the reported sequence of the HSV-1(17)syn+ strain. (FIG. 1a–1d) To ensure that the antibody to a predicted repeat sequence, Ala-Thr-Pro, reacted with ICP34.5 rather than with a heterologous protein with a similar repeat sequence, a short sequence of 45 nucleotides that encodes an epitope characteristic of another HSV-1 gene was inserted near the 5' terminus of the ICP34.5-coding domain. The recombinant virus expressed a protein with an appropriately slower electrophoretic mobility and which reacted with both the monoclonal antibody to the inserted epitope and rabbit antiserum to the Ala-Thr-Pro repeat element.

Studies of the identification of the genes associated with neurovirulence have repeatedly implicated DNA sequences located at or near a terminus of the long component of HSV-1 DNA. Thus, Centifanto-Fitzgerald et al. (*J. Exp. Med.*, 155: 475, 1982) transferred, by means of a DNA

fragment, a virulence marker from a virulent to an antivirulent strain of HSV-1. Deletion of genes located at one terminus of the long component of HSV-1 DNA contributed to the lack of virulence exhibited by a prototype HSV vaccine strain. Meignier et al., *J. Infect. Dis.*, 158: 602 (1988). In other studies, Javier et al. (*J. Virol.*, 65: 1978, 1987) and Thompson et al. (*Virology*, 172: 435, 1989) demonstrated that an HSV-1 $\times$ HSV-2 recombinant virus consisting largely of HSV-1 DNA but with HSV-2 sequences located at one terminus of the long component was avirulent; virulence could be restored by rescue with the homologous HSV-1 fragment. Taha et al. (*J. Gen. Virol.*, 70: 705, 1989) described a spontaneous deletion mutant lacking 1.5 kbp at both ends of the long component of a HSV-2 strain. Because of heterogeneity in the parent virus population, the loss of virulence could not be unambiguously related to the specific deletion, although the recombinant obtained by marker rescue was more virulent than the deletion mutant. In neither study was a specific gene or gene product identified at the mutated locus, and no gene was specifically linked to virulence phenotype.

#### Role of the $\gamma_1$ 34.5 Gene

To test the possible role of the product of the  $\gamma_1$ 34.5 gene, ICP34.5, a series of four viruses (FIG. 2) were genetically engineered by the procedures of Post and Roizman (*Cell*, 25: 227, 1981, incorporated herein by reference).

1) Recombinant virus R4002 (FIG. 4a, lane 3 and FIG. 4b, lane 3) contained the insertion of a thymidine kinase (tk) gene driven by the promoter of the  $\alpha$ 27 gene ( $\alpha$ 27-tk) in both copies of the ICP34.5 coding sequences. It was constructed by cotransfected rabbit skin cells with intact DNA of HSV-1(F) $\Delta$ 305, a virus from which a portion of the tk gene was specifically deleted, with the DNA of plasmid pRB3615, which contains the  $\alpha$ 27-tk gene inserted into the  $\gamma_1$ 34.5 gene contained in the BamHI S fragment. Recombinants that were tk $^+$  were then selected on human 143 thymidine kinase minus (TK $^-$ ) cells. The fragment containing the  $\alpha$ 27-tk gene contains downstream from the tk gene: the 5' untranscribed promoter, the transcribed noncoding sequence, and the initiating methionine codon of the glycoprotein H gene. The BstEII site into which the  $\alpha$ 27-tk fragment was inserted is immediately upstream of the codon 29 of the  $\gamma_1$ 34.5 open reading frame. As a consequence, the initiating codon of glycoprotein H was fused in frame and became the initiating codon of the truncated open reading frame of the  $\gamma_1$ 34.5 gene (FIG. 2, line 3). The recombinant selected for further study, R4002, was shown to contain the  $\alpha$ 27-tk gene insert in both copies of  $\gamma_1$ 34.5 gene (FIG. 3a, lane 4 and FIG. 3b, lane 4) and specified only the predicted truncated product of the chimeric  $\gamma_1$ 34.5 gene (FIG. 4b). The amounts of the native ICP34.5 protein detected in these and previous studies have been generally low. The chimeric genes formed by the fusion of the 5' transcribed noncoding region and the initiating codon of glycoprotein H in frame with the truncated  $\gamma_1$ 34.5 gene were expressed far more efficiently than the native genes.

2) The recombinant virus R3617 (FIG. 2, line 5 from the top) lacking 1 kb of DNA in each copy of the  $\gamma_1$ 34.5 gene was generated by cotransfected rabbit skin cells with intact R4002 DNA and the DNA of plasmid pRB3616. In this plasmid, the sequences containing most of the coding domain of  $\gamma_1$ 34.5 has been deleted (FIG. 2, line 5 from top). The tk $^-$  progeny of the transfection was plated on 143TK $^-$  cells overlaid with medium containing bromodeoxy uridine (BrdU). This procedure selects tk $^-$  viruses, and since the tk gene is present in both copies of the  $\gamma_1$ 34.5 gene, the selected progeny of the transfection could be expected to contain

deletions in both copies. The selected tk $^-$  virus designated as R3617 was analyzed for the presence of the deletion in both copies of the  $\gamma_1$ 34.5 gene. For assays of neurovirulence, the deletion in the native tk $^-$  gene of R3617, which traces its origin from HSV-1(F) $\Delta$ 305, had to be repaired. This was done by cotransfected rabbit skin cells with intact R3617 DNA and BamHI Q fragment containing the tk gene. The virus selected for tk $^+$  phenotype in 143TK $^-$  cells was designated R3616. This virus contains a wild-type BamHI Q fragment (FIG. 3b lane 6) and does not make ICP34.5 (FIG. 4b).

3) To ascertain that the phenotype of R3616 indeed reflects the deletion in the  $\gamma_1$ 34.5 gene, the deleted sequences were restored by cotransfected rabbit skin cells with intact R3617 DNA, the HSV-1(F) BamHI Q DNA fragment containing the intact tk gene, and the BamHI SP DNA fragment containing the intact  $\gamma_1$ 34.5 gene in the molar ratios of 1:1:10, respectively. Viruses that were tk $^+$  were then selected in 143TK $^-$  cells overlaid with medium containing hypoxanthine, aminopterin, and thymidine. The tk $^+$  candidates were then screened for the presence of wild-type tk and  $\gamma_1$ 34.5 genes. As expected, the selected virus designated HSV-1(F)R (FIG. 2, line 6) contained a wild-type terminal long component fragment (compare FIG. 3a, lanes 2, 7, and 8), and expressed ICP34.5 (FIG. 4a, lane 6).

4) To eliminate the possibility that the phenotype of R3616 reflects deletion in cryptic open reading frames, a virus was constructed (R4010, FIG. 2, line 7 from the top) that contains translational stop codons in all three reading frames in the beginning of the ICP34.5 coding sequence. The 20-base oligonucleotide containing the translational stop codons and its complement sequence (FIG. 2) were made in an Applied Biosystems 380D DNA synthesizer, mixed at equal molar ratio, heated to 80° C., and allowed to cool slowly to room temperature. The annealed DNA was inserted into the HSV-1(F) BamHI S fragment at the BstEII site. The resulting plasmid pRB4009 contained a stop codon inserted in the beginning of the ICP34.5 coding sequence. The 20 nucleotide oligomer DNA insertion also contained a Spe I restriction site, which allowed rapid verification of the presence of the insert. To generate the recombinant virus R4010, rabbit skin cells were cotransfected with the intact DNA of R4002 and the pRB4009 plasmid DNA. Recombinants that were tk $^-$  were selected in 143TK $^-$  cells in medium containing BrdU. The tk $^+$  version of this virus, designated R4009, was generated by cotransfected of intact tk $^-$  R4010 DNA with HSV-1(F) BamHI Q DNA fragment, and selection of tk $^+$  progeny. The virus selected for neurovirulence studies, R4009, contained the Spe I restriction endonuclease 50 cleavage site in both BamHI S and SP fragments (compare FIG. 3a, lanes 9 and 10) and did not express ICP34.5 (FIG. 4b, lane 7).

5) R4004 (FIG. 2, last line) was a recombinant virus produced by insertion of a sequence encoding 16 amino acids. This sequence has been shown to be the epitope of the monoclonal antibody H943 reactive with a viral protein designated as ICP4. Hubenthal-Voss et al., *J. Virol.*, 62: 454 (1988). The virus was generated by cotransfected intact R4002 DNA and the DNA of plasmid pRB3976 containing the insert, and the selected tk $^-$  progeny was analyzed for the presence of the insert. For neurovirulence studies, its tk gene was restored (recombinant virus R4003) as described above. The DNA sequence was inserted in frame at the Nco I site at the initiating methionine codon of the  $\gamma_1$ 34.5 gene. The insert regenerated the initiating methionine codon and generated a methionine codon between the epitope and the remainder of ICP34.5. Because of the additional amino

acids, the protein migrated more slowly in denaturing polyacrylamide gels (FIG. 4b, lane 4).

Plaque morphology and size of all of the recombinants were similar to those of the wild-type parent, HSV-1(F) when plated on Vero, 143TK<sup>-</sup>, and rabbit skin cells lines. Whereas HSV-1(F)R and R4003 replicated as well as the wild-type virus in replicate cultures of Vero cells, the yields of R3616 and R4009 were reduced to one-third to one-fourth the amount of the wild type. Although ICP34.5 was not essential for growth of HSV-1 in cells in culture, the results of the studies shown in Table 1 indicate that the deletion or termination of translation of the  $\gamma_134.5$  has a profound effect on the virulence of the virus. Thus, all of the mice inoculated with the highest concentration [ $1.2 \times 10^6$  plaque-forming units (PFU)] of R3616 survived. In the case of R4009, only three of ten mice died as a result of inoculation with the highest concentration of virus ( $\sim 10^7$  PFU). In comparison with other deletion mutants, R3616 and R4009 rank among the least pathogenic viruses reported to date. The virus in which the  $\gamma_134.5$  gene was restored exhibited the virulence of the parent virus.

TABLE 1

Virus in the inoculum	Genotype	PFU/LD <sub>50</sub>
HSV-1(F)	Wild-type parent virus	420
R3616	1000-bp deletion in the $\gamma_134.5$	>1,200,000
HSV-1(F)R	Restoration of $\gamma_134.5$ and tk	130
R4009	Stop codon in $\gamma_134.5$	>10,000,000
R4003	Monoclonal antibody epitope inserted at the NH <sub>2</sub> terminal	4,200

Comparative ability of wild-type and recombinant viruses to cause death after intracerebral inoculation of mice. The neurovirulence studies were done on female BALB/C mice obtained at 21 days of age (weight  $\pm 1.8$  g) from Charles River Breeding Laboratories in Raleigh, North Carolina. The viruses were diluted in minimum essential medium containing Eagle's salts and 10% fetal bovine serum, penicillin, and gentamicin. The mice were inoculated intracerebrally in the right cerebral hemisphere with a 26-gauge needle. The volume delivered was 0.03 ml, and each dilution of virus was tested in groups of ten mice. The animals were checked daily for mortality for 21 days. The LD<sub>50</sub> was calculated with the aid of the "Dose effect Analysis" computer program from Elsevier Biosoft, Cambridge, United Kingdom.

The wild-type virus and all of the recombinants have identical surface glycoproteins necessary for attachment and penetration into brain cells. Injection of 106 PFU into the brain should result in infection and death of a significant number of the brain cells. Death after intracerebral inoculation results from viral replication, spread from cell to cell, and cell destruction before the immune system has a chance to act. Titrations of brain tissue suspended in minimal essential medium containing Eagle's salts and 10% fetal bovine serum showed that the brains of animals inoculated with the viruses that failed to make ICP34.5 contained very little virus. Thus, for the R3616 and R4009 viruses, the recovery was 120 and 100 PFU per gram of brain tissue, respectively. Given the amount of virus in the inoculum (highest concentration tested), it is not clear whether the small amounts of recovered virus represent a surviving fraction of the inoculum or newly replicated virus. In contrast, the amounts of virus recovered from mice inoculated with HSV-1(F)R and R4003 were  $6 \times 10^6$ , respectively. These results indicate that the failure of the two recombinant viruses to cause death must be related to poor spread of virus in neuronal tissue as a consequence of the inability of mutant viruses to replicate in the CNS, reflecting a reduction in their host range.

In the course of studies designed to determine the function of the  $\gamma_134.5$  gene product, it was discovered that infection

of cells of neuronal origin with mutants incapable of expressing the  $\gamma_134.5$  gene resulted in shutoff of cellular protein synthesis, whereas infection of cells of non neuronal origin with wild type or mutant viruses resulted in sustained protein synthesis and production of infectious progeny.

## EXAMPLE 1

IMPACT OF  $\gamma_134.5$  EXPRESSION ON PROGRAMMED CELL DEATH

## Materials and Methods

## Cells

Vero cells originally obtained from ATCC were propagated in DME media containing 5% calf serum. The human SK-N-SH neuroblastoma (NB) cell line was obtained from ATCC (HTB11) and propagated in Dulbecco's modified Eagle's medium containing 10% fetal bovine serum.

## Viruses

The isolation of herpes simplex virus 1 strain F, [HSV-1 (F)] has been described by Ejercito et al. (*J. Gen. Virol.*, 2: 357-364 (1968) (incorporated herein by reference). The construction of recombinant viruses R3616, R4009, and HSV-1(F) was reported by Chou et al. (*Science*, 250: 1262-1266, Nov. 30, 1990) (incorporated herein by reference). As illustrated in FIG. 5, R3616 contains a 1 Kbp deletion in both copies of the  $\gamma_134.5$  gene. In the recombinant R4009 a stop codon was inserted in both copies of the  $\gamma_134.5$  gene. The  $\gamma_134.5$  genes in the recombinant R3616 were restored to yield the recombinant HSV-1(F)R.

## Virus Infection

Cells were generally exposed to the viruses for 2 h at 37° C. at multiplicity of infection of 5 and then removed and replaced with the 199v media containing 1% calf serum. The infection continued at 37° C. for a length of time as indicated for each experiment. Cells were then either labeled for de novo protein synthesis or analysis of viral DNA and RNA. <sup>35</sup>S-methionine labeling

At the indicated time post infection, 50 uCi of <sup>35</sup>S-methionine (specific activity >1,000 Ci/mmol, Amersham Co., Downers Grove, Ill.) was added to 1 ml of 199v media lacking methionine to cells in 6 well dishes. Labeling was continued for 1.5 hr, at which time cells were harvested. Preparation of cell extracts; separation of proteins by electrophoresis in denaturing polyacrylamide gels crosslinked with N,N' Diallyltartardiamide (Bio-Rad Laboratories, Richmond, Calif.); transfer of polypeptides to nitrocellulose sheets; autoradiography and immunoblot with antibodies have been described by Ackermann et al., *J. Virol.*, 52: 108-118 (1984) (incorporated herein by reference).

## Results

HSV-1 recombinant viruses lacking the  $\gamma_134.5$  gene induce the shut off protein synthesis in neuroblastoma cells. In the course of screening human cell lines derived from CNS tissues it was apparent that the SK-N SH neuroblastoma cell lines produced 100 fold less mutant viruses than the fully permissive Vero cells. It was also noted that the SK-N-SH neuroblastoma cells infected with R3616 or with R4009 exhibited reduced protein synthesis in cells harvested at 7 hours (FIG. 6a) and ceased to incorporate <sup>35</sup>S-methionine by 13 hours (FIG. 6b) post infection. The phenomenon was observed in SK-N-SH neuroblastoma cells only, and could be attributed specifically to the mutations in the  $\gamma_134.5$  gene inasmuch as restoration of the deleted sequences yielded a virus [HSV-1(F)R] which expressed viral proteins at 13 hour post infection (FIG. 6b) and exhibited the parental, wild type phenotype.

The shut off of protein synthesis occurred after the expression of  $\alpha$  genes. Viral genes form three major groups whose expression is coordinately regulated and sequentially ordered in a cascade fashion. See Roizman and Sears, *Fields' Virology*, 2 ed., Fields et al., Eds, 1795–1841 (1990). The  $\alpha$  genes do not require de novo protein synthesis for their expression, the  $\beta$  genes which are required for the synthesis of viral DNA require prior synthesis of functional  $\alpha$  and  $\beta$  proteins and the onset of viral DNA synthesis. To determine the point at which expression of viral gene functions was terminated in SK-N-SH neuroblastoma cells infected with mutant viruses, infected cell lysates electrophoretically separated in denaturing polyacrylamide gels were transferred to a nitrocellulose sheet and probed with antibody to an  $\alpha$  ( $\alpha27$ ), a  $\beta$  (viral thymidine kinase) and two abundant  $\gamma$  proteins. Roller and Roizman (*J. Virol.*, 65: 5873–5879 (1991) have shown that the latter were the products of  $U_L26.5$  and of  $U_S11$  genes whose expression at optimal levels requires viral DNA synthesis. As shown in FIGS. 7a–7c, the SK-N-SH neuroblastoma cells infected with the mutant viruses made normal amounts of  $\alpha27$  protein (FIG. 7a), reduced amounts of the thymidine kinase ( $\beta$ ) protein (FIG. 7b), but no detectable  $\gamma$  proteins (FIGS. 7a and 7b). In contrast, both the wild type and mutant viruses could not be differentiated with respect to their capacity to replicate or to direct the synthesis of their proteins in Vero cells (FIGS. 7a–7c).

The signal for shut off of protein synthesis is linked to viral DNA synthesis. These experiments were designed to determine whether the shutoff of protein synthesis was linked to a gene whose expression was dependent on viral DNA synthesis. The results of a key experiment are shown in FIG. 8. Replicate SK-N-SH and Vero cell cultures were infected with HSV-1(F) and recombinant viruses and maintained in the presence or absence of inhibitory concentrations of phosphonoacetate, a drug which blocks viral DNA synthesis. The cells were pulse labeled with  $S^{35}$ -methionine at 13 h post infection. The salient feature of the results were that protein synthesis in SK-N-SH cells infected with either R3616 or R4009 was sustained for at least 13 h in the presence of Phosphonoacetate but not in its absence. These results indicated that the signal for cessation of protein synthesis in SK-N-SH neuroblastoma cells infected with mutant viruses was associated with viral DNA synthesis or with a  $\gamma$  gene dependent on viral DNA synthesis for its expression.

Human neuroblastoma cells infected with the  $\gamma_134.5$  mutants synthesized viral DNA and accumulated late mRNA even though the shut off of protein synthesis precluded accumulation of late proteins. The evidence presented above indicated that in SK-N-SH neuroblastoma cells an event associated with viral DNA synthesis triggered the shut off of protein synthesis and that the late ( $\gamma$ ) viral proteins did not accumulate. We expected, therefore, little or no accumulation of viral DNA and in the absence of viral DNA synthesis, little or no accumulation of late ( $\gamma$ ) viral transcripts whose synthesis is dependent on viral DNA synthesis. To our surprise, the amounts of viral DNA recovered from SK-N-SH neuroblastoma cells 17 hours post infection with mutant viruses were comparable to those obtained from wild type parent or repaired [(HSV-1)F]R] viruses (FIG. 9a). Furthermore, while the SK-N-SH neuroblastoma cells did not synthesize demonstrable amounts of  $U_S11$  protein, the amounts of  $U_S11$  gene transcripts which accumulated in cells infected with mutant and wild type viruses were of similar magnitude (FIG. 9b).

The significance of these results stems from three observations. First, in infected cells, protein synthesis reflects a

regulatory cascade; a protein synthesis is replaced by  $\beta$  and later by  $\gamma$  protein synthesis. In all cell lines other than the SK-N-SH neuroblastoma cells infected with the  $\gamma_134.5$  mutants and tested to date, a block in the synthesis of one group of proteins does not lead to a cessation of total protein synthesis. For example, in cells treated with inhibitors of DNA synthesis like PAA, a subclass of  $\gamma$  proteins dependent for their synthesis on viral DNA synthesis is not made. However, in these cells,  $\beta$  protein synthesis continues beyond the time of their synthesis in untreated infected cells. The striking observations made in the studies on SK-N-SH cells infected with the  $\gamma_134.5$  null mutants are that (i) all protein synthesis ceased completely, (ii) viral DNA was made and (iii) late,  $\gamma$  mRNA exemplified by  $U_S11$  mRNA was made even though protein synthesis ceased. These manifestations for viral replication have not been reported previously and are not characteristic of cells infected with wild type virus or any mutant virus infection of cells (e.g. Vero, HEp-2, baby hamster kidney, 143tk<sup>−</sup> and rabbit skin cell lines and human embryonic lung cells strain) other than those described in this report.

Second, the function of the  $\gamma_134.5$  gene is to overcome this block in protein synthesis in SK-N-SH cells since repair of the mutation restores the wild type phenotype.

Lastly, while the association of cessation of protein synthesis with the onset of viral DNA replication does not exclude the possibility that a product made after infection is responsible of the shut off, the data does support the hypothesis that the cessation of protein synthesis is specifically caused by a known viral gene product interacting with the protein synthesizing machinery of the cell. For example, it has been well established that the product of the HSV-1 gene designated a vhs can shut off cellular protein synthesis after infection. vhs is a structural protein of the virus and is introduced into cells during infection. It destabilizes mRNA early in infection and its effects are not dependent on viral gene products made after infection. In the experiments set forth above, protein synthesis of wild type and mutant viruses could not be differentiated at 13 hours post infection in cells treated with Phosphonoacetate and hence the phenotype of mutant viruses cannot be attributed to the vhs gene product. This conclusion is reinforced by the observation that viral protein synthesis in SK-N-SH cells was not affected by increasing the multiplicity of infection with wild type virus to values as high as 100 pfu/cell (data not shown). A more likely source for the genetic information for the cessation of protein synthesis is the cell itself.

It has been reported that deprivation of growth factors from cells of neuronal origins results in programmed cell death, which manifests itself initially by the cessation of protein synthesis and subsequently by fragmentation of DNA. Apoptosis in lymphocytes is manifested by degradation of DNA. In the case of other herpes viruses, it has been shown that in B lymphocytes infected with the Epstein-Barr virus, the product of the viral IMP-1 gene induces the host gene Bcl-2 which precludes programmed lymphocyte death (Henderson et al, *Cell* 65: 1107–1991. Thus, it is apparent that the onset of viral DNA synthesis in neuronal cells triggers programmed cell death by cessation of protein synthesis and that HSV-1  $\gamma34.5$  gene precludes this response.

The evolution of a HSV-1 gene which would preclude a response to a neuronal stress is not surprising. Infection of neurons, especially sensory neurons, is an essential feature of viral reproductive lifestyle which enables the HSV-1 to remain latent and to survive in human populations. If, as we propose, the function of  $\gamma_134.5$  gene is to preclude cell death,

the target of the gene would be neurons rather than lymphocytes since HSV normally infects nerve cells.

The  $\gamma_134.5$  gene has several unusual features. The gene lacks a conventional TATAA box or response elements frequently associated with TATAA-less transcriptional units. The sequence which enables the expression of the gene is 12 bp long but repeated as many as 3 times in the wild type strain used in this laboratory. Various assays reported elsewhere indicate that the amounts of gene products produced in cells of non neuronal derivation are smaller than those expressed by most viral genes and that the amounts of the protein made in the absence of viral DNA synthesis were smaller than those made in its presence. The gene is predicted to encode a protein of 263 amino acids. It contains the triplet Ala-Thr-Pro repeated 10 time and accumulates in the cytoplasm. A recent note indicates that 63 amino acid residues near the carboxyl terminus of the  $\gamma_134.5$  protein shares 83% identity with a mouse protein MyD116 found in a myeloid leukemic cell line induced to differentiate by interleukin 6 (Lord et al., *Nucleic Acid Res.* 18: 2823, 1990). The function of MyD116 is unknown. The results presented above demonstrate that the product of the  $\gamma_134.5$  gene, the protein ICP34.5, quite clearly enables sustained protein synthesis in SK-N-SH neuroblastoma cells, and it is clear that the gene's expression is sufficient to preclude apoptosis.

The promoter-regulatory elements essential for the expression of  $\gamma_134.5$  are contained within three elements of the  $\alpha$  sequence, i.e. the direct repeats DR2 and DR4 and the unique  $U_b$  sequences. Gel retardation assays failed to show binding of the product of the  $\alpha 4$  gene encoding the major regulatory protein of the virus to any of the elements regulating expression of the  $\gamma_134.5$  gene. In transient expression assays, the product of the  $\alpha 4$  or of  $\alpha 0$  genes failed to transactivate a chimeric reporter gene consisting of the coding sequences of the thymidine kinase gene fused to the 5' non-coding sequences of the  $\gamma_134.5$  gene. The reporter gene was induced, but to a relatively low level by co-transfection with plasmids containing both  $\alpha 4$  and  $\alpha 0$  genes. The plasmid encoding the  $\alpha 27$  gene had no effect on the expression of the chimeric reporter gene transfected alone although it reduced the induction of the chimeric gene by plasmids containing the  $\alpha 0$  and  $\alpha 4$  genes.

## EXAMPLE 2

### TREATMENT OF PROGRAMMED CELL DEATH (APOPTOSIS) WITH GENE THERAPY

In this example,  $\gamma_134.5$  gene therapy directed toward the prevention or treatment of apoptosis is described. For the purposes of this example mutated HSV-1 virus is proposed as a vector for introduction of the gene into neuronal cells undergoing or about to undergo programmed cell death. It is also envisioned that this embodiment of the present invention could be practiced using alternative viral or phage vectors, including retroviral vectors and vaccinia viruses whose genome has been manipulated in alternative ways so as to render the virus nonpathogenic. The methods for creating such a viral mutation are set forth in detail in U.S. Pat. No. 4,769,331, incorporated herein by reference. Furthermore, it is also envisioned that this embodiment of the present invention could be practiced using any gene whose expression is beneficial in gene therapy, and use of the non-HSV viruses would allow gene therapy in non-neuronal systems.

Herpes simplex virus has a natural tropism for human CNS tissue. Under wild type conditions, the virus is capable

of replicating and multiplying in the nervous system and is neurovirulent. The virus can also establish latent infection in the neurons and can be occasionally reactivated. To establish a vector system for delivery of genes into neurons, the proposed construct of an HSV vector must satisfy the following criteria: 1. Such a vector should have a natural tropism for CNS and brain tissue. 2. Such a vector should be non-pathogenic; that is, totally avirulent and not reactivatable to cause an infection. 3. Such a vector should consist of 10 constitutive expression of  $\gamma_134.5$  to prevent cell death in cells undergoing neurodegeneration. 4. Such a vector so proposed in 3 is suitable for additional foreign gene insertion for gene therapy.

## Material and Methods

A HSV vector with a mutational lesion in the  $\alpha 4$  gene is constructed. The proposed virus will no longer be able to replicate, multiply and reactivate from latent infection in the CNS. The virus can, in the absence of  $\alpha 4$  gene, establish a latent infection in the neuron. This virus can be obtained by co-transfection of viral DNA with plasmid containing a  $\alpha 4$  expressing cell line.  $\alpha 4$  expressing cell lines and the virus have been reported previously. DeLuca et al., *J. Virol.*, 56: 558-570 (1985).

Additionally, such an HSV vector with  $\gamma_134.5$  gene under a constitutive expression promoter is also envisioned. This constitutive expression promoter can be the HSV LAT promoter, the LTR promoter of retrovirus or any other foreign promoter specific for neural gene expression. Such a viral vector properly introduced is suitable for prevention of cell death in neuronal cells undergoing apoptosis.

Moreover, such an HSV vector with foreign genes inserted at a neutral location on the viral genome is suitable for delivery of foreign genes into target neurons and for CNS gene therapy. The procedures to generate the above recombinant viruses are those published by Post and Roizman (*Cell*, 25: 227, 1991) incorporated herein by reference. See also U.S. Pat. No. 4,769,331, incorporated herein by reference.

In instances where use of the mutated HSV-1 virus is appropriate the virus can be combined with a pharmaceutically acceptable carrier such as buffered saline and injected at the site of peripheral nerve endings whose axons originate from neural cell bodies undergoing or about to undergo apoptosis. As will be recognized by those skilled in the medical arts the amount of virus administered will vary depending upon several factors, including the vector's ability to target the cells requiring treatment, the extent to which the gene is expressed in the target tissue, and the activity of the expressed protein, among others. An inoculum containing approximately  $10^4$ - $10^5$  viruses in phosphate buffered saline or skim milk has produced successful results in mice. Virus so injected is taken up into the peripheral nerve endings and is then transported via retrograde axonal transport to the neuronal cell bodies. In instances where such peripheral injection is not useful or appropriate, localized intraspinal or intraventricular injection, or direct microinjection of the virus could be utilized.

An appropriately altered non-HSV virus, one with a genome manipulated in such a way as to render the virus non-pathogenic, could be used in a similar manner. Direct microinjection or peripheral injection for delivery to the cell body via retrograde axonal transport are options for viral delivery. Finally, it should also be noted that a biological functional equivalent gene could be utilized for gene therapy in any vector described in this example.

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## EXAMPLE 3

USE OF MULTI-POTENT NEURAL CELL LINES TO DELIVER THE  $\gamma_1$ 34.5 GENE TO THE CNS

In addition to the viral vector delivery system to CNS and brain tissue, another vector system has been developed recently using cell lines passaged in vitro and engrafting these cells back to the animal. These procedures involve taking cells of fetal or postnatal CNS origin, immortalizing and transforming them in vitro and transplanting the cells back into the mouse brain. These cells, after engraftment, follow the migration pattern and environmental cue of normal brain cell development and differentiate in a nontumorigenic, cytoarchitecturally appropriate manner. This work has been exemplified in several articles notably Snyder et al., *Cell*, 68: 33–51, 1992 and Ranfranz et al., *Cell*, 66: 713–729, 1991. Utilizing appropriately modified techniques, it is possible to introduce the  $\gamma_1$ 34.5 gene alone or in combination with other genes of interest into the cells and engraft. Such a procedure allows the delivery of the genes to its natural site. Proper expression of the  $\gamma_1$ 34.5 gene in these neurons should result in prevention of cell death in neurodegeneration and preserving cells carrying foreign genes suitable for gene therapy.

## Materials and Methods

## Propagation of Cerebellar Cell Lines

Cerebellar cell lines are generated as described by Ryder et al. (*J. Neurobiol.* 21: 356–375, 1990). Lines are grown in Dulbecco's modified Eagle's medium supplemented with 10% fetal calf serum (Gibco), 5% horse serum (Gibco), and 2 mM glutamine on poly-L-lysine (PLL) (Sigma) (10  $\mu$ g/ml)-coated tissue culture dishes (Corning). The lines are maintained in a standard humidified, 37°C, 5% CO<sub>2</sub>-air incubator and are either fed weekly with one-half conditioned medium from confluent cultures and one-half fresh medium or split (1:10 or 1:20) weekly or semiweekly into fresh medium.

Transduction of Cerebellar Progenitor Lines with  $\gamma_1$ 34.5 Gene

A recent 1:10 split of the cell line of interest is plated onto 60 mm tissue culture plates. Between 24 and 48 hr after plating, the cells are incubated with the replication-incompetent retroviral vector BAG containing the -myc gene (10<sup>6</sup>–10<sup>7</sup> colonyforming units [cfu]/ml) plus 8  $\mu$ g/ml polybrene for 1–4 hr for introduction of the  $\gamma_1$ 34.5 gene alone or in combination with other suitable genes for gene therapy, along with the neomycin G418 marker. Cells are then cultured in fresh feeding medium for approximately 3 days until they appear to have undergone at least two doublings. The cultures are then trypsinized and seeded at low density (50–5000 cells on a 100 mm tissue culture dish). After approximately 2 weeks well-separated colonies are isolated by brief exposure to trypsin within plastic cloning cylinders. Colonies are plated in 24-well PLL-coated CoStar plates. At confluence, these cultures are passaged to 60 mm tissue culture dishes and expanded. A representative dish from each subclone is stained directly in the culture dish using X-gel histochemistry (see Price et al., 1967; Cepko, 1989a, 1989b). The percentage of blue cells is determined under the microscope. Subclones with the highest percentage of blue cells (ideally >90%; at least >50%) are maintained, characterized, and used for transplantation.

## Tests for Virus Transmission

The presence of helper virus is assayed by measurement of reverse transcriptase activity in supernatants of cells lines

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as described by Goff et al. (1981) and by testing the ability of supernatants to infect NIH 3T3 cells and generate G418-resistant colonies of X-gal<sup>+</sup> colonies (detailed in Cepko, 1989a, 1989b). All cerebellar cell lines used for transplantation are helper virus-free as judged by these methods.

## Coculture of Neural Cell Lines with Primary Cerebellar Tissue

Primary dissociated cultures of neonatal mouse cerebellum are prepared as in Ryder et al. (1990) and seeded at a density of 2×10<sup>6</sup> to 4×10<sup>6</sup> cells per PLL-coated eight-chamber Lab Tek glass or plastic slide (Miles). After the cells settled (usually 24 hr), 10% of a nearly confluent 10 cm dish of the neural cell line of interest is seeded, following trypsinization, onto the slide. The coculture is re-fed every other day and grown in a 50% CO<sub>2</sub>-air, humified incubator until 8 or 14 days of coculture.

## Preparation of Cells Lines for Transplantation

Cells from a nearly confluent but still actively growing dish of donor cells are washed twice with phosphate-buffered saline (PBS), trypsinized, gently triturated with a wide-bore pipette in serum-containing medium (to inactivate the trypsin), gently pelleted (1100 rp for 1 min in a clinical centrifuge), and resuspended in 5 ml of PBS. Washing by pelleting and resuspension of fresh PBS is repeated twice, with the cells finally resuspended in a reduced volume of PBS to yield a high cellular concentration (at least 1×10<sup>6</sup> cells per  $\mu$ l). Trypan blue (0.05% w/v) is added to localize the inoculum. The suspension is kept well triturated, albeit gently, and maintained on ice prior to transplantation to minimize clumping.

## Injections into Postnatal Cerebellum

Newborn CD-1 or CF-1 mice are cryoanesthetized, and the cerebellum is localized by transillumination of the head. Cells are administered either via a Hamilton 10  $\mu$ l syringe with a beveled 33-gauge needle or a drawn glass micropipette with a 0.75 mm inner diameter and 1.0 mm outer diameter generated from borosilicate capillary tubing (FHC, Brunswick, Me.) by a Flaming Brown Micropipette Puller (Model p-87, Sutter Instruments) using the following parameters: heat 750, pull 0, velocity 60, time 0. Best results are achieved with the glass micropipette. The tip is inserted through the skin and skull into each hemisphere and vermis of the cerebellum where the cellular suspension was injected (usually 1–2  $\mu$ l per injection). Typically, the following situation should exist: 1×10<sup>7</sup> cells per ml of suspension; ×10<sup>6</sup> to 2×10<sup>6</sup> cells per injection; one injection in each cerebellar hemisphere and in the vermis. Importantly, the cellular suspension, maintained on ice throughout, is gently triturated prior to each injection in order to diminish clumping and to keep cells suspended.

The injection of BAG virus was performed as described for the cell suspension. The BAG virus stock (8×10<sup>7</sup> G418-resistant cfu/ml) contained, in addition to trypan blue, polybrene at 8  $\mu$ g/ml.

## EXAMPLE 4

## TREATMENT OF PROGRAMMED CELL DEATH (APOPTOSIS) WITH ICP34.5

As an alternative to the gene therapy methods described for exemplary purposes in Examples 2 and 3, neuronal cells undergoing or about to undergo programmed cell death can also be treated with the protein expressed by the  $\gamma_1$ 34.5 gene, i.e. ICP34.5. Alternatively, a biological functional equivalent protein could be used in such treatment.

For example, ICP34.5 is isolated from cells expressing the protein and purified using conventional chromatography

purification and immunoaffinity purification methods described by Ackerman et al. (*J. Virol.* 58: 843-850, 1986, incorporated herein by reference). The purified protein is next combined with a pharmaceutically appropriate carrier, such as buffered saline or purified distilled water. For administration, the pharmaceutical composition can be injected in one of several ways, as appropriate: (i) intraspinal injection; (ii) intraventricular injection; (iii) direct injection into the area containing the neurons undergoing or about to undergo programmed cell death or any other appropriate method of administration understood by those skilled in the art. Such treatment would be particularly appropriate in the surgical repair of severed peripheral nerves, and the use of proteins as therapeutic agents is well within the current level of skill in the medical arts in light of the present specification.

#### EXAMPLE 5

##### ASSAYS FOR CANDIDATE SUBSTANCES FOR PREVENTION OF PROGRAMMED CELL DEATH (APOPTOSIS)

The  $\gamma_134.5$  gene of herpes simplex virus enables the virus to replicate, multiply and spread in the central nervous system and the brain so that the virus is neurovirulent to the host. Recombinant virus lacking the gene lost this ability to penetrate the CNS of the host and become totally avirulent. In examining the nature of this avirulent phenotype in culture, the mutant virus lacking the gene exhibited a total translation shutoff phenotype characteristic of programmed cell death. This mechanism of programmed cell death afforded by the host cell greatly reduced the ability of the virus to multiply and spread. The function of  $\gamma_134.5$  in the virus therefore is to inactivate the programmed death of the cell (anti-apoptosis) thereby restoring translation and enabling the virus to replicate to full potential in the host.

This anti-apoptotic effect of  $\gamma_134.5$  was further examined and its ability to protect neural cells from other environmental stresses which lead to apoptosis was discovered. These environmental stresses include UV, nerve growth factor deprivation and neuronal cell differentiation. This Example describes the use of the  $\gamma_134.5$  gene and its protective function to screen for pharmaceutical agents and drugs that mimic the *in vivo* function of  $\gamma_134.5$  to prevent neurodegeneration. Such a screening procedure constitutes construction of cell lines expressing  $\gamma_134.5$  and a null cell line without the gene and measurement of the viability of the cells after stress treatment by induction of a reporter gene. This can be a host gene promoter tagged by a fluorescence indicator or any other easily assayable marker to signal viability.

#### Materials and Methods

A test neuroblastoma cell line is established constitutively expressing  $\gamma_134.5$  and containing a fluorescence tagged (e.g., the  $\alpha$  sequence promoter fused to lacZ) cellular gene, or any tag that provides the easily assayable marker to signal viability. A neuroblastoma null cell line consisting of a-lacZ indicator gene and the same host indicator gene is also established, along with a Vero cell line consisting of a-lacZ indicator gene and the same host indicator gene. Environmental stresses are then applied that normally would (1) trigger the  $\alpha$  sequence promoter activation; (2) trigger the protection afforded by  $\gamma_134.5$  as signaled by viability after stress treatment; and (3) trigger cell programmed death in the absence of  $\gamma_134.5$ . Candidate substances of pharmaceu-

tically appropriate drugs and agents can be tested in such an assay. The proposed scheme of the assay for scoring of positive candidates is shown in outline form in Table 2.

TABLE 2

##### EXPERIMENTAL FLOW CHART: ASSAY FOR CANDIDATE SUBSTANCE ABLE TO PREVENT PROGRAMMED CELL DEATH

	CELL LINES	ACTION	EXPECTATION
10	A. neuroblastoma cells constitutively express $\gamma_134.5$ and a second inducible promoter-indicator gene	stress followed by induction of second promoter	viability as measured by induction of a reporter gene hours after stress
20	B. neuroblastoma cells expressing $\alpha$ -lacZ and a second inducible promoter	stress followed by induction of second promoter	1. apoptosis related stress: $\alpha$ -lacZ induced; second promoter not induced 2. toxicity: no induction of $\alpha$ -lacZ and the second inducible promoter
25	C. vero cells expressing $\alpha$ -lacZ and a second inducible promoter gene	stress followed by induction	1. $\alpha$ -lacZ not induced 2. toxicity factor excluded, determined from expression of inducible second promoter
30			

#### EXAMPLE 6

##### ASSAY FOR CANDIDATE SUBSTANCES FOR ACTIVATION OF PROGRAMMED CELL DEATH (APOPTOSIS) FOR TREATMENT OF CANCER OR TUMOROGENDIC DISEASES AND FOR SUPPRESSION OF HSV INFECTION

In order to induce cell death in tumor cells, it is desirable to block the expression of the anti-apoptosis gene or the activity of the protein expressed by the gene. As such, it is desirable to develop procedures that will allow screening for candidate substances which trigger cell death in tumor cells. In addition, since expression of the  $\gamma_134.5$  gene of HSV-1 has been shown to prevent apoptosis in neuronal cells so that the virus can replicate, multiply and spread in the CNS (that is, so that the virus can become neurovirulent), a substance capable of blocking  $\gamma_134.5$  expression or inhibiting the action of ICP34.5 can be expected to suppress HSV neurovirulence (or the virulence of other viruses relying on a similar mechanism) by allowing apoptosis to occur in infected neurons.

It has been found that the protection afforded by  $\gamma_134.5$  can be extended to protect other cells from environmental stresses, and indeed the gene has a generalized anti-apoptotic effect. The promoter for the gene  $\gamma_134.5$  lies in the  $\alpha$  sequence of HSV and, at time of stress, the promoter is activated. It can be assumed that the  $\alpha$  sequence promoter contains apoptosis responsive elements and cellular factors (transcription factors in particular) that mediate the expression of anti-apoptosis gene are apoptotic in nature. These cellular factors are therefore the targets of the present assay to screen for drugs or agents that would inactivate their ability to induce the anti-apoptosis gene. The assay involves the use of the  $\alpha$  sequence promoter and its inducibility by conditions which induce apoptosis as an indicator assay

which screens for therapeutic agents and drugs capable of blocking the expression of the anti-apoptosis gene and therefore allow the cell to die of programmed cell death.

A test plasmid construct bearing the a sequence and coding sequence up to the 28th amino acid of  $\gamma_134.5$  is fused to the lacZ reporter gene or any other readily assayable reporter gene. The construct is introduced into a neuroblastoma or PC12 cell line by G418 selection and a clonal and continuous cell line for screening purposes is established. A control plasmid construct bearing an HSV late promoter, a promoter which would normally not be expressed in cell lines and which further would not be induced to express by apoptosis-inducing stress is fused to the same indicator gene. This construct is also introduced into a continuous clonal cell line and serves as a control for the test cell line. Environmental stresses that trigger the a sequence promoter activation and that cause programmed cell death are then defined. These conditions include UV injury, virus infection, nerve growth factor deprivation, and the influence of antibodies on cell surface receptors, among others. Candidate substances or pharmaceutically appropriate drugs and agents are then tested in assays for their ability to block the a sequence promoter activation at time of stress.

The assay of the present invention allows the screening and identification of pharmaceutically appropriate drugs and agents targeted at various cellular factors that induce the expression of anti-apoptosis gene. By inactivating essential cellular factors, these agents should be able to allow cell programmed death to occur. Such positive candidates would then be appropriately administered (via intravenous, intrathecal, or direct injection, or via oral administration) in order to induce programmed cell death in tumor cells, in neurons infected with the herpes virus, or in cells infected with a virus the virulence of which is dependent upon an anti-apoptotic effect. The use of proteins and other chemotherapeutic substances in antitumor therapy is well known in the art, and therefore, it is considered that the use and dosages of candidate substances for treatment of tumorigenic diseases (e.g., cancer) or herpes infection is well within the skill of the present state of the medical arts in light of the present specification. See U.S. Pat. Nos. 4,457,916; 4,529,594; 4,447,355; and 4,477,245, all incorporated herein by reference. These positive candidates can also be used to identify intermediates in the pathways leading to cell programmed death.

#### Materials and Methods

W5 cell lines are established in 96 well culture dishes coated with collagen. Control cell lines containing the promoter fusion element are also established in such 96 well dishes. The test candidate substances are added to the medium in individual wells containing both the test and control cell lines set up in 96 well dishes. The cells are then briefly exposed to UV or other stresses. 8 hr post stress induction, cells are washed with PBS-A twice, and fixed with 0.5 ml containing 2% (v/v) formaldehyde and 0.2% glutaraldehyde in PBS for 5 min at room temperature. The cells are rinsed again with PBS and then stained with 2 ml 5 mM potassium ferrocyanide, 5 mM potassium ferricyanide, 2 mM MgCl<sub>2</sub> and 1mg/ml X-gal (diluted from a 40 mg/ml stock solution in dimethyl sulfoxide) in PBS. Cells expressing  $\beta$ -Galactosidase were stained blue after incubation at 37° C. for 23 days.

#### Results

The construct described above with the lacZ reporter gene was introduced into PC12 cell line. A new cell line W5 was

clonally established by G418 selection. The W5 cell line was then tested for activation of the a sequence promoter under suboptimal conditions names in 3 above. The results are: (a) The above cells, when exposed briefly to UV for 2 minutes, turn blue upon staining the fixed cells with X-gal at 6–10 hr post UV exposure. (b) The above cells, when exposed to HSV-1(F) virus at multiplicity of infection of 5, also turn blue upon staining at 8 hr post infection. (c) The above cells turn light blue when nerve growth factor (rat, 7S) is introduced into the medium to allow differentiation processes. (d) The cells turn darker blue when Nerve Growth Factor is removed from the medium after differentiation is complete and the cells have become dependent on nerve growth factor for survival. (e) Little or no difference in color development is seen in cells starved for serum (0% fetal bovine serum) and those fully supplied in 10% fetal bovine serum. (f) The above experiments are repeated with control promoter fusion elements to control for the true inhibition of antiapoptosis gene expression rather than toxicity-induced cell death. By this procedure, the positive candidates that can induce cell death in cells will therefore render the following phenotypes: (i) Introduction of stress to the test cell line in the absence of this substance will give rise to blue colored cells. (ii) Introduction of stress to the test cell line in the presence of same substance will give rise to white cells. (iii) Introduction of stress to control cell lines with our without this putative substance will have no effect on the color of cells.

The present invention has been disclosed in terms of specific embodiments which are believed by the inventors to be the best modes for carrying out the invention. However, in light of the disclosure hereby provided, those of skill in the various arts will recognize that modifications can be made without departing from the intended scope of the invention. The exemplary embodiments set forth herein and all other modifications and embodiments are intended to be within the scope and spirit of the present invention and the appended claims.

#### REFERENCES CITED

- 40 Ackerman et al., *J. Virol.*, 58: 843 (1986)
- Ackermann et al., *J. Virol.*, 52: 108–118 (1984)
- Centifanto-Fitzgerald et al., *J. Exp. Med.*, 155: 475, 1982
- Chou and Roizman *Cell*, 41: 803–811, 1985
- Chou and Roizman *J. Virol.*, 64: 1014–1020, 1990
- Chou et al., *Science*, 250: 1212–1266, 1990
- Clem et al., *Science*, 245: 1388–1390, Nov. 29, 1991
- Corey and Spear, *N. Eng. J. Med.*, 314: 686–691, 1986
- DeLuca et al., *J. Virol.*, 56: 558–570 (1985)
- Ejercito et al., *J. Gen. Virol.*, 2: 357–364 (1968)
- Hayward et al., *Proc. Natl. Acad. Sci. USA*, 72: 4243–4247 (1975)
- Henderson et al., *Cell*, 65: 1107–1115, 1991
- Honess and Roizman (*J. Virol.*, 12: 1346 (1973))
- Honess and Roizman, *J. Virol.*, 12: 1347–1365 (1973)
- Hubenthal-Voss et al., *J. Virol.*, 62: 454 (1988)
- Itoh et al., *Cell* 66: 233–243 (1991)
- Javier et al. (*J. Virol.*, 65: 1978, 1987) and Thompson et al., *Virology*, 172: 435, 1989
- Johnson et al., *Neurobiol. of Aging*, 10: 549–552, 1989
- Katz et al., *J. Virol.*, 64: 4288–4295
- Kyte et al., *J. Mol. Biol.*, 157: 105–132, 1982
- Lord et al., *Nucleic Acid Res.* 18: 2823, 1990
- Mackem and Roizman, *J. Virol.*, 44: 934–947 (1982)
- McGeoch et al., *J. Gen. Virol.*, 64: 1531–1574 (1988)
- Meignier et al., *J. Infect. Dis.*, 158: 602 (1988)
- Peppel and Baglioni *BioTechniques*, 9: 711–712, 1990

**29**

Post and Roizman *Cell*, 25: 227, 1981  
 Ranfranz et al., *Cell*, 66: 713–729, 1991  
 Roizman and Sears, *Fields' Virology*, 2 ed., Fields et al.,  
 Eds, 1795–1841 (1990)  
 Roller and Roizman *J. Virol.*, 65: 5873–5879 (1991)  
 Ryder et al. *J. Neurobiol.* 21: 356–375, 1990

**30**

Sentman et al. *Cell*, 67: 879–88, Nov. 29, 1991  
 Snyder et al., *Cell*, 68: 33–51, 1992  
 Strasser et al. *Cell*, 67: 889–899, Nov. 29, 1991  
 Taha et al. *J. Gen. Virol.*, 70: 705, 1989  
<sup>5</sup> Wadsworth et al., *J. Virol.*, 15: 1487–1497 (1975)  
 Williams, *Cell*, 85; 1097–1098

## SEQUENCE LISTING

## (1) GENERAL INFORMATION:

(iii) NUMBER OF SEQUENCES: 43

## (2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 17 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

TTTAAAGTCG CGGGGGC

17

## (2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 133 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

GCAGCCCGGC CCCCCGGCGGC CGAGACGAGC GAGTTAGACA GGCAAGCACT ACTCGCCTCT 60

GCACGCACAT GCTTGCTGT CAAACTCTAC CACCCGGCA CGCTCTCTGT CTCCATGGCC 120

CGCCGCCGCC GCC 133

## (2) INFORMATION FOR SEQ ID NO:3:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 291 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

ATCGCGGCC CGGCCGCCCG CGGCCACGGG CGCCGTCCA ACCGCACAGT 60

CCCAGGTAAC CTCCACGCC AACTCGAAC CGCGGTCAG GAGCGCGCC GCAGCCGCC 120

CGCCGCCAGC CCCCCCGAGT GGGCCCCGC CTTCTTGTTC GCTGCTGCTG CGCCAGTGGC 180

TCCACGTTCC CGAGTCCGCG TCCGACGACG ACGATGACGA CGACTGGCCG GACAGCCCC 240

CGCCCGAGCC GGCGCCAGAG GCGCGGCCCA CGCGCCGCCGC CCCCCGCC 291

## (2) INFORMATION FOR SEQ ID NO:4:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 595 base pairs  
 (B) TYPE: nucleic acid

-continued

(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

ACCGCCCCGGC GCGGGGCCGG GGGGCGGGGC TAACCCCTCC CACCCCCCCT CACGCCCTT	60
CCGCCTTCGG CGCGCCCTCG CCCTCCGCCT GCGCGTCACC GCAGAGCACC TGGCGCGCCT	120
GCGCCTGCGA CGCGCGGGCG GGGAGGGGGC GCCGGAGCCC CCCGCGACCC CGCGGACCCC	180
CGCGACCCCC CGGACCCCCG CGACCCCCCG GACCCCCCGG ACCCCCCGGA CCCCCCGCGAC	240
CCCCCGCGACC CCCGCGCGGG TGCGCTTCTC GCCCCCACGTC CGGGTGCGCC ACCTGGTGGT	300
CTGGGCCTCG GCCGCCCCGCC TGCGCGCGCG CGGCTCGTGG GCCCGCGAGC GGGCCGACCG	360
GGCTCGGTTTC CGGCGCCGGG TGGCGGAGGC CGAGGCGGTC ATCGGGCGT GCCTGGGGCC	420
CGAGGCCCCGT GCCCAGGGCC TGGCCCGCGG AGCCGGCCCG GCGAACCTCGG TCTAACGTTA	480
CACCCGAGGC GGCGCTGGGTC TTCCGCGGAG CTCCCGGGAG CTCCGCACCA AGCCGCTCTC	540
CGGAGAGACG ATGGCAGGAG CGCGCATAT ATACGCTGGG AGCCGGCCCG CCCCC	595

(2) INFORMATION FOR SEQ ID NO:5:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 291 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

GAGGCAGGGCC CGCCCTCGGA GGGCGGGACT GGCCAATCGG CGGCCGCCAG CGCGCGGGG	60
CCCGGCCAAC CAGCGTCCGC CGAGTCTTCG GGGCCCGGCC CACTGGCGG GAGTTACCGC	120
CCAGTGGGCC GGGCCGCCCA CTTCCCGGTA TGGTAATTAA AAACCTACAA GAGGCCTTGT	180
TCCGCTTCCC GGTATGGTAA TTAGAAACTC ATTAATGGGC GGCCCCGGCC GCCCTTCCCG	240
CTTCCGGCAA TTCCGCGGGC CCTTAATGGG CAACCCCGGT ATTCCCCGCC T	291

(2) INFORMATION FOR SEQ ID NO:6:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 150 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

TTTAAAGCGG TGGCGCGGG CAGCCCGGGC CCCCCGCCGA GACTAGCGAG TTAGACAGGC	60
AAGCACTACT CGCCTCTGCA CGCACATGCT TGCCTGTCAA ACTCTACCAAC CCCGGCACGC	120
TCTCTGTCTC CATGGCCCGC CGCCGCCGCC	150

(2) INFORMATION FOR SEQ ID NO:7:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 503 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

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## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

ATCGGGCCCC CGGCCGCCCC CGGCCGCCCC GGCCCACGGG CGCCGTCCA ACCGCACAGT	60
CCCAGGTAAC CTCCACGCCA AACTCGGAAC CCGCGGTCAG GAGCGGCCCG GCGGCCGCC	120
CGCCGCCGCC CCCCGCCGGT GGGCCGCCCG CTTCTTGTTG GCTGCTGCTG CGCCAGTGGC	180
TCCACGTTCC CGAGTCCGCG TCCGACGACG ACGATGACGA CGACTGGCCG GACAGCCCC	240
CGCCCGAGTC GGCAGAGAG GCCCGGCCCA CGCCGCCCGC CCCCCGCCCG CCGGGCCCGC	300
ACCGCCCGGC GTGGGGCCGG GGGGGGGGG TGACCCCTCC CACCCCCCTT CGCGCCCGTT	360
CCGCCTTCCG CGCGCCTCG CCCTCCGCT GCGCGTCACC GCGGAGCACC TGGCGCGCCT	420
GCGCCTGCGA CGCGCGGGCG GGGAGGGGGC GCCGGAGCCC CCCGCGACCC CGCGACCCC	480
CGCGACCCCC CGGACCCCCG CGA	503

## (2) INFORMATION FOR SEQ ID NO:8:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 368 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

CCCCCGCGAC CCCCGCGCGG GTGCGCTTCT CGCCCCACGT CCGGGTGCAC CACCTGGTGG	60
TCTGGGCCTC GGGCGCCCGC CTGGCGCGCC GCGGCTCGTG GGCCCGCGAG CGGGCCGACC	120
GGGCTCGGTT CCGGCGCCGG GTGGCGGAGG CCGAGGCGGT CATCGGGCCG TGCCTGGGGC	180
CCGAGGCGCG TGCCCGGGCC CTGGCCCGCG GAGCCGGCCC GGCGAACTCG GTCTAACGTT	240
ACACCCGAGG CGGCCTGGGT CTTCCGCGGA GCTCCCGGGA GCTCCGACCC AAGCCGCTCT	300
CCGGAGAGAC GATGGCAGGA GCCGCGCATA TATACGCTTG GAGCCAGCCC GCCCTCACAG	360
GGCGGGCC	368

## (2) INFORMATION FOR SEQ ID NO:9:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 271 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

GGGGGGGACT GGCAATCGG CGGCCGCCAG CGCGGCGGGG CCCGGCCAAC CAGCGTCCGC	60
CGAGTCTTCG GGGCCCGGCC CATTGGCGG GAGTTACCGC CCAATGGGCC GGGCCGCCA	120
CTTCCCGGTA TGGTAATTAA AAACTTGCAA GAGGCCTTGT TCCGCTTCCC GGTATGGTAA	180
TTAGAAACTC ATTAATGGGC GGCCCGGGCC GCCCTTCCCG CTTCCGGCAA TTCCCGGGC	240
CCTTAATGGG CAACCCCGGT ATTCCCCGCC T	271

## (2) INFORMATION FOR SEQ ID NO:10:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 11 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

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(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

TTTAAAGTCA C

11

(2) INFORMATION FOR SEQ ID NO:11:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 256 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

AGCGGGGGGC AGCCCCCCC CGGCCGAGAC TAGCGAGTTA GACAGGCAAG CACTACTCGC	60
CTCTGCACGC ACATGCTTGC CTGTCAAACCT TACCCACCC GGCACGCTCT CTGTCCTCCAT	120
GGCCCGCCGC CGCCGCCGCC ATCGCCGCC CGCCGCCCG CGGCCACGGG	180
CGCGGTCCA ACCGCACAGT CCCAGGTAAC CTCCACGCC AACTCGGAAC CGTGGTCAG	240
GAGCGCGCCC CGGGCC	256

(2) INFORMATION FOR SEQ ID NO:12:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 154 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

GGTGGGCCCC CGCCTTCTTG TTCGCTGCTG CTGCGCCAGT GGCTCACGT TCCCGAGTCC	60
GCGTCCGACG ACCGACGATGA CGACGACTGG CGGGACAGCC CCCCGCCCGA GCCGGCGCCA	120
GAGGCCCGGC CCACCGCCGC CGCCCCCCGC CCCC	154

(2) INFORMATION FOR SEQ ID NO:13:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 212 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

ACCGCCCGGC GCGGGCCCGG GGGGCGGGGC TAACCCCTCC CACCCCCCTT CACGCCCTT	60
CCGCCTTCCG CCGCGCCTCG CCCTCCGCCT GCGCGTCACC GCGGAGCACC TGGCGCGCCT	120
GCGCCTGCGA CGCGCGGGCG GGGAGGGGGC GCCGAAGCCC CCCGCGACCC CGCGACCC	180
CGCGACCCCCC CGGACCCCCG CGACCCCCGC GA	212

(2) INFORMATION FOR SEQ ID NO:14:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 356 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

**-continued**

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:14:

CCCCCGCGAC	CCCCGCGCGG	GTGCGCTTCT	CGCCCCACGT	CCGGGTGCAG	CACCTGGTGG	60
TCTGGGCCTC	GGCGGCCCGC	CTGGCGCGCC	GCGGCTCGTG	GGCCCGCGAG	CGGGCCGACC	120
GGGCTCGGTT	CCGGCGCCGG	GTGGCGGAGG	CCGAGGCGGT	CATCGGGCCG	TGCCTGGGC	180
CCGAGGCCCG	TGCCCCGGCC	CTGGCCCGCC	GAGCCGGCCC	GGCGAACCTCG	GTCTAACGTT	240
ACACCCGAGG	CGGCCTGGGT	CTTCGCGGGA	GCTCCCGGGA	GCTCCACACC	AAGCCGCTCT	300
CCGGAGAGAC	GATGGCAGGA	GCCGCGCATA	TATACGCTGG	GAGCCGGCCC	GCCCCC	356

(2) INFORMATION FOR SEQ ID NO:15:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 291 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:15:

GAGGCGGGCC	CGCCCTCGGA	GGCGGGACT	GGCCAATCGG	CGGCCGCCAG	CGCGCGGGG	60
CCCGGCCAAC	CAGCGTCCGC	CGAGTCGTGG	GGGCCGGCC	CACTGGCGG	TAACTCCCG	120
CCAGTGGGCC	GGGCCGCCCA	CTTCCCGGTA	TGGTAATTAA	AAACTTGCAA	GAGGCCTTGT	180
TCCGCTTCCC	GGTATGGTAA	TTAGAAAATC	ATTAATGGGC	GGCCCCGGCC	GCCCTTCCCG	240
CTTCCGGCAA	TTCCCGCGGC	CCTTAATGGG	CAACCCCGGT	ATTCCCCGCC	T	291

(2) INFORMATION FOR SEQ ID NO:16:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 10 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:16:

TTTAAAGCGC					10
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(2) INFORMATION FOR SEQ ID NO:17:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 431 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:17:

GGCGGGCGGGC	AGCCCCCCC	CGGCCGAGAC	TAGCGAGTTA	GACAGGCAAG	CACTACTCGC	60
CTCTGCACGC	ACATGCTTGC	CTGTCAAAT	CTACCAACCC	GGCACGCTCT	CTGTCTCCAT	120
GGCCCGCCGC	CGCCGCCGCC	ATCGCGGCC	CCGCGGCC	CGGCCGCCCG	GGCCACGGG	180
CGCGGTCCCA	ACCGCACAGT	CCCAGGTAAC	CTCCACGCC	AACTCGGAAC	CCGTGGTCAG	240
GAGCGCGCCC	CGGGCCGCC	CGCCGCCGCC	CCCCGCCGT	GGGCCCCCGC	CTTCTTGTTC	300
GCTGCTGCTG	CGGCAGTGGC	TCCAGGTTCC	GGAGTCCCG	TCCGACGACG	ACGATGACGA	360

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CGACTGGCCG GACAGCCCC CGCCCGAGCC GGCGCCAGAG GCCCGGCCA CCGCCGCCGC	420
CCCCCGCCCC C	431

## (2) INFORMATION FOR SEQ ID NO:18:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 212 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:18:

ACCGCCCGGC GCGGGCCCAG GGGGCGGGGC TGACCCCTCC CACCCCCCTT CACGCCCTT	60
CCGCCTTCG CCGCGCTTCG CCCTCCGCT GCAGCGTCACC GCAGAGCACC TGGCGCGCCT	120
GCGCTCTGCA CGCGCGGGCG GGGAGGGGGC GCCGGAGCCC CCCGCGACCC CCGCGACCCC	180
CGCGACCCCC GCGACCCCCG CGACCCCCGC GA	212

## (2) INFORMATION FOR SEQ ID NO:19:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 356 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:19:

CCCCCGCGAC CCCCGCGCGG GTGCGTTCT CGCCCCACGT CCGGGTGCAC CACCTGGTGG	60
TCTGGGCCTC GGGCGCCCGC CTGGCGCGCC GCGGCTCGTG GGCCCGCGAG CGGGCCGACC	120
GGGCTCGGTT CCGGCGCCGG GTGGCGGAGG CCGAGGCGGT CATCGGGCCG TGCCTGGGCC	180
CCAAGGCCCC CGCCCGGGCC CTGGCCCGCG GAGCGGGCCC GGCGAACTCG GTCTAACGTT	240
ACACCCGAGG CGGCCTGGGT CTTCCGCGGA GCTCCGGGA GCTCCACACC AAGCCGCTCT	300
CCGGAGAGAC GATGGCAGGA GCCGCGATA TATACGCTGG GAGCCGGCCC GCCCCCC	356

## (2) INFORMATION FOR SEQ ID NO:20:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 291 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:20:

GAGGCGGGCC CGCCCTCGGA GGGCGGGACT GGCCAATCGG CGGCCGCCAG CGCGCGGGGG	60
CCCGGCCAAC CAGCGTCCGC CGAGTCGTGG GGGCCGGCC CACTGGCGG TAACTCCCGC	120
CCAGTGGGCC GGGCGGCCCA CTTCCCGGTA TGGTAATTAA AAACTTGCAA GAGGCCTTGT	180
TCCGCTTCCC GGTATGGTAA TTAGAAACTC ATTAATGGGC GGCCCCGGCC GCCCTTCCCG	240
CTTCCGGCAA TTCCCGCGGC CCTTAATGGG CAACCCCGGT ATTCCCCGTC T	291

## (2) INFORMATION FOR SEQ ID NO:21:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 20 base pairs  
 (B) TYPE: nucleic acid

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(C) STRANDEDNESS: single	
(D) TOPOLOGY: linear	
(ii) MOLECULE TYPE: DNA (genomic)	
(xi) SEQUENCE DESCRIPTION: SEQ ID NO:21:	
GTAACCTAGA CTAGTCTAGC	20
(2) INFORMATION FOR SEQ ID NO:22:	
(i) SEQUENCE CHARACTERISTICS:	
(A) LENGTH: 20 base pairs	
(B) TYPE: nucleic acid	
(C) STRANDEDNESS: single	
(D) TOPOLOGY: linear	
(ii) MOLECULE TYPE: DNA (genomic)	
(xi) SEQUENCE DESCRIPTION: SEQ ID NO:22:	
GTTACGCTAG ACTAGTCTAG	20
(2) INFORMATION FOR SEQ ID NO:23:	
(i) SEQUENCE CHARACTERISTICS:	
(A) LENGTH: 58 base pairs	
(B) TYPE: nucleic acid	
(C) STRANDEDNESS: single	
(D) TOPOLOGY: linear	
(ii) MOLECULE TYPE: DNA (genomic)	
(xi) SEQUENCE DESCRIPTION: SEQ ID NO:23:	
CCCGGACATG GAACGAGTAC GACGACGCAG CCGACGCCGC CGGCGACCGG GCCCCGGG	58
(2) INFORMATION FOR SEQ ID NO:24:	
(i) SEQUENCE CHARACTERISTICS:	
(A) LENGTH: 51 base pairs	
(B) TYPE: nucleic acid	
(C) STRANDEDNESS: single	
(D) TOPOLOGY: linear	
(ii) MOLECULE TYPE: DNA (genomic)	
(xi) SEQUENCE DESCRIPTION: SEQ ID NO:24:	
CTGCTCATGC TGCTGCGTCG GCTGCGCGG CCGCTGGCCC GGGGCCCGTA C	51
(2) INFORMATION FOR SEQ ID NO:25:	
(i) SEQUENCE CHARACTERISTICS:	
(A) LENGTH: 6 amino acids	
(B) TYPE: amino acid	
(C) STRANDEDNESS: single	
(D) TOPOLOGY: linear	
(ii) MOLECULE TYPE: peptide	
(xi) SEQUENCE DESCRIPTION: SEQ ID NO:25:	
Met Ala Arg Arg Arg Arg	
1                         5	
(2) INFORMATION FOR SEQ ID NO:26:	
(i) SEQUENCE CHARACTERISTICS:	
(A) LENGTH: 258 amino acids	
(B) TYPE: amino acid	
(C) STRANDEDNESS: single	
(D) TOPOLOGY: linear	

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(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:26:

His	Arg	Gly	Pro	Arg	Arg	Pro	Arg	Pro	Pro	Gly	Pro	Thr	Gly	Ala	Val
1			5			10						15			

Pro	Thr	Ala	Gln	Ser	Gln	Val	Thr	Ser	Thr	Pro	Asn	Ser	Glu	Pro	Ala
	20			25								30			

Val	Arg	Ser	Ala	Pro	Ala	Ala	Ala	Pro	Pro	Pro	Pro	Ala	Ser	Gly	
	35			40								45			

Pro	Pro	Pro	Ser	Cys	Ser	Leu	Leu	Leu	Arg	Gln	Trp	Leu	His	Val	Pro
	50			55					60						

Ala	Glu	Ser	Ala	Ser	Asp	Trp	Pro	Asp	Ser						
	65			70			75					80			

Pro	Pro	Pro	Glu	Pro	Ala	Pro	Glu	Ala	Arg	Pro	Thr	Ala	Ala	Ala	Pro
	85			90					95						

Arg	Pro	Arg	Ser	Pro	Pro	Pro	Gly	Ala	Gly	Pro	Gly	Gly	Ala	Asn	
	100				105					110					

Pro	Ser	His	Pro	Pro	Ser	Arg	Pro	Phe	Arg	Leu	Pro	Pro	Arg	Leu	Ala
	115				120					125					

Leu	Arg	Leu	Arg	Val	Thr	Ala	Glu	His	Leu	Ala	Arg	Leu	Arg	Leu	Arg
	130				135				140						

Arg	Ala	Gly	Gly	Glu	Gly	Ala	Pro	Glu	Pro	Pro	Ala	Thr	Pro	Ala	Thr
	145			150				155				160			

Pro	Ala	Thr	Pro												
	165			170				175							

Ala	Thr	Pro	Ala	Thr	Pro	Ala	Arg	Val	Arg	Phe	Ser	Pro			
	180				185				190						

His	Val	Arg	Val	Arg	His	Leu	Val	Val	Trp	Ala	Ser	Ala	Ala	Arg	Leu
	195				200					205					

Ala	Arg	Arg	Gly	Ser	Trp	Ala	Arg	Glu	Arg	Ala	Asp	Arg	Ala	Arg	Phe
	210			215				220							

Arg	Arg	Arg	Val	Ala	Glu	Ala	Glu	Ala	Val	Ile	Gly	Pro	Cys	Leu	Gly
	225			230			235			240					

Pro	Glu	Ala	Arg	Ala	Arg	Ala	Leu	Ala	Arg	Gly	Ala	Gly	Pro	Ala	Asn
	245			250				255							

Ser Val

(2) INFORMATION FOR SEQ ID NO:27:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 6 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:27:

Met	Ala	Arg	Arg	Arg	Arg										
1			5												

(2) INFORMATION FOR SEQ ID NO:28:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 169 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

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(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:28:

His	Arg	Gly	Pro	Arg	Arg	Pro	Arg	Pro	Pro	Gly	Pro	Thr	Gly	Ala	Val
1			5			10				15					
Pro	Thr	Ala	Gln	Ser	Gln	Val	Thr	Ser	Thr	Pro	Asn	Ser	Glu	Pro	Ala
	20					25				30					
Val	Arg	Ser	Ala	Pro	Ala	Ala	Ala	Pro	Pro	Pro	Pro	Ala	Gly	Gly	
	35					40				45					
Pro	Pro	Pro	Ser	Cys	Ser	Leu	Leu	Leu	Arg	Gln	Trp	Leu	His	Val	Pro
	50					55			60						
Glu	Ser	Ala	Ser	Asp	Asp	Asp	Asp	Asp	Asp	Trp	Pro	Asp	Ser	Pro	
	65					70			75			80			
Pro	Pro	Glu	Ser	Ala	Pro	Glu	Ala	Arg	Pro	Thr	Ala	Ala	Ala	Pro	Arg
		85					90				95				
Pro	Pro	Gly	Pro	His	Arg	Pro	Ala	Trp	Ala	Arg	Gly	Ala	Gly	Leu	Thr
		100					105			110					
Pro	Pro	Thr	Pro	Pro	Arg	Ala	Pro	Ser	Ala	Phe	Arg	Arg	Ala	Ser	Pro
		115					120			125					
Ser	Ala	Cys	Ala	Ser	Pro	Arg	Ser	Thr	Trp	Arg	Ala	Cys	Ala	Cys	Asp
	130					135				140					
Ala	Arg	Ala	Gly	Arg	Gly	Arg	Arg	Ser	Pro	Pro	Arg	Pro	Pro	Arg	Pro
	145					150			155			160			
Pro	Arg	Pro	Pro	Arg	Pro	Pro	Arg	Pro							
		165													

(2) INFORMATION FOR SEQ ID NO:29:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 180 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:29:

Pro	Arg	Gly	Cys	Ala	Ser	Arg	Pro	Thr	Ser	Gly	Cys	Ala	Thr	Trp	Trp
1				5			10			15					
Ser	Gly	Pro	Arg	Pro	Pro	Ala	Trp	Arg	Ala	Ala	Ala	Arg	Gly	Pro	Ala
	20					25			30						
Ser	Gly	Pro	Thr	Gly	Leu	Gly	Ser	Gly	Ala	Gly	Trp	Arg	Arg	Pro	Arg
	35				40				45						
Arg	Ser	Ser	Gly	Arg	Ala	Trp	Gly	Pro	Arg	Pro	Val	Pro	Gly	Pro	Trp
	50					55			60						
Pro	Ala	Glu	Pro	Ala	Arg	Arg	Thr	Arg	Ser	Asn	Val	Thr	Pro	Glu	Ala
	65					70			75			80			
Ala	Trp	Val	Phe	Arg	Gly	Ala	Pro	Gly	Ser	Ser	Ala	Pro	Ser	Arg	Ser
	85					90			95						
Pro	Glu	Arg	Arg	Trp	Gln	Glu	Pro	Arg	Ile	Tyr	Thr	Leu	Gly	Ala	Ser
	100					105			110						
Pro	Pro	Ser	Gln	Gly	Gly	Pro	Pro	Arg	Gly	Arg	Asp	Trp	Pro	Ile	Gly
	115					120			125						
Gly	Arg	Gln	Arg	Gly	Gly	Ala	Arg	Pro	Thr	Ser	Val	Arg	Arg	Val	Phe
	130					135			140						
Gly	Ala	Arg	Pro	Ile	Gly	Arg	Glu	Leu	Pro	Pro	Asn	Gly	Pro	Arg	Arg
	145					150			155			160			

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Pro	Leu	Pro	Gly	Met	Val	Ile	Lys	Asn	Leu	Gln	Glu	Ala	Leu	Phe	Arg
				165				170				175			
Phe	Pro	Val	Trp												
			180												

## (2) INFORMATION FOR SEQ ID NO:30:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 46 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: protein

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:30:

Met	Ala	Arg	Arg	Arg	Arg	Arg	His	Arg	Gly	Pro	Arg	Arg	Pro	Arg	Pro
1							5	10				15			

Pro	Gly	Pro	Thr	Gly	Ala	Val	Pro	Thr	Ala	Gln	Ser	Gln	Val	Thr	Ser
							20	25				30			

Thr	Pro	Asn	Ser	Glu	Pro	Val	Val	Arg	Ser	Ala	Pro	Ala	Ala		
							35	40			45				

## (2) INFORMATION FOR SEQ ID NO:31:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 126 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: protein

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:31:

Gly	Gly	Pro	Pro	Pro	Ser	Cys	Ser	Leu	Leu	Leu	Arg	Gln	Trp	Leu	His
1								5	10			15			

Val	Pro	Glu	Ser	Ala	Ser	Asp	Trp	Pro	Asp						
							20	25				30			

Ser	Pro	Pro	Pro	Glu	Pro	Ala	Pro	Glu	Ala	Arg	Pro	Thr	Ala	Ala	Ala
							35	40			45				

Pro	Arg	Pro	Arg	Ser	Pro	Pro	Gly	Ala	Gly	Pro	Gly	Gly	Gly	Ala	
	50					55			60						

Asn	Pro	Ser	His	Pro	Pro	Ser	Arg	Pro	Phe	Arg	Leu	Pro	Pro	Arg	Leu
65						70		75			80				

Ala	Leu	Arg	Leu	Arg	Val	Thr	Ala	Glu	His	Leu	Ala	Arg	Leu	Arg	Leu
						85		90			95				

Arg	Arg	Ala	Gly	Gly	Glu	Gly	Ala	Pro	Lys	Pro	Pro	Ala	Thr	Pro	Ala
						100		105			110				

Thr	Pro	Ala	Thr	Pro											
	115				120				125						

## (2) INFORMATION FOR SEQ ID NO:32:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 73 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: protein

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:32:

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Ala	Arg	Val	Arg	Phe	Ser	Pro	His	Val	Arg	Val	Arg	His	Leu	Val	Val
1				5			10						15		

Trp	Ala	Ser	Ala	Ala	Arg	Leu	Ala	Arg	Arg	Gly	Ser	Trp	Ala	Arg	Glu
	20				25							30			

Arg	Ala	Asp	Arg	Ala	Arg	Phe	Arg	Arg	Arg	Val	Ala	Glu	Ala	Glu	Ala
	35				40					45					

Val	Ile	Gly	Pro	Cys	Leu	Gly	Pro	Glu	Ala	Arg	Ala	Arg	Ala	Leu	Ala
	50				55			60							

Arg	Gly	Ala	Gly	Pro	Ala	Asn	Ser	Val							
	65				70										

## (2) INFORMATION FOR SEQ ID NO:33:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 179 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:33:

Met	Ala	Arg	Arg	Arg	Arg	Arg	His	Arg	Gly	Pro	Arg	Arg	Pro	Arg	Pro
1							5		10				15		

Pro	Gly	Pro	Thr	Gly	Ala	Val	Pro	Thr	Ala	Gln	Ser	Gln	Val	Thr	Ser
	20					25				30					

Thr	Pro	Asn	Ser	Glu	Pro	Val	Val	Arg	Ser	Ala	Pro	Ala	Ala	Ala	Pro
	35					40				45					

Pro	Pro	Pro	Pro	Ala	Gly	Gly	Pro	Pro	Pro	Ser	Cys	Ser	Leu	Leu	Leu
	50				55					60					

Arg	Gln	Trp	Leu	Gln	Val	Pro	Glu	Ser	Ala	Ser	Asp	Asp	Asp	Asp	Asp
	65				70			75			80				

Asp	Asp	Trp	Pro	Asp	Ser	Pro	Pro	Glu	Pro	Ala	Pro	Glu	Ala	Arg	
	85				90					95					

Pro	Thr	Ala	Ala	Ala	Pro	Arg	Pro	Arg	Ser	Pro	Pro	Pro	Gly	Ala	Gly
	100					105					110				

Pro	Gly	Gly	Gly	Ala	Asp	Pro	Ser	His	Pro	Pro	Ser	Arg	Pro	Phe	Arg
	115				120				125						

Leu	Pro	Pro	Arg	Leu	Ala	Leu	Arg	Leu	Arg	Val	Thr	Ala	Glu	His	Leu
	130					135				140					

Ala	Arg	Leu	Arg	Leu	Arg	Arg	Ala	Gly	Gly	Glu	Gly	Ala	Pro	Glu	Pro
	145						150		155			160			

Pro	Ala	Thr	Pro												
	165					170			175						

Ala Thr Pro

## (2) INFORMATION FOR SEQ ID NO:34:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 73 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:34:

Ala	Arg	Val	Arg	Phe	Ser	Pro	His	Val	Arg	Val	Arg	His	Leu	Val	Val
1				5			10					15			

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Trp Ala Ser Ala Ala Arg Leu Ala Arg Arg Gly Ser Trp Ala Arg Glu  
20 25 30

Arg Ala Asp Arg Ala Arg Phe Arg Arg Arg Val Ala Glu Ala Glu Ala  
35 40 45

Val Ile Gly Pro Cys Leu Gly Lys Glu Ala Arg Ala Arg Ala Leu Ala  
50 55 60

Arg Gly Ala Gly Pro Ala Asn Ser Val  
65 70

## (2) INFORMATION FOR SEQ ID NO:35:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 18 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: peptide

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:35:

Met Asp Glu Tyr Asp Asp Ala Ala Asp Ala Ala Gly Asp Arg Ala Pro  
1 5 10 15

Gly Met

## (2) INFORMATION FOR SEQ ID NO:36:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 1327 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: DNA (genomic)

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:36:

TTTAAAGTCG CGCGGGCGCA GCCCCGCCCG CCGCGGCCGA GACGAGCGAG TTAGACAGGC	60
AAGCACTACT CGCCCTTGCA CGCACATGCT TGCCTGTCAA ACTCTACCAC CCCGGCACGC	120
TCTCTGTCTC CATGGCCCGC CGCCGCCGCC ATCGCGGCC CCGCCGCCCG CGGCCGCCCG	180
GGCCCACGGG CGCCGTCCCA ACCGCACAGT CCCAGGTAAC CTCCACGCC AACTCGAAC	240
CCGGGGTCAG GAGCGCGGCC CGGGCCGCC CGCCGCCCG CCCGCCAGT GGGCCCCCGC	300
CTTCCTTGTTC GCTGCTGCTG CGCCAGTGGC TCCACGTTCC CGAGTCCGCG TCCGACGACG	360
ACGATGACGA CGACTGGCCG GACAGCCCC CGCCCGAGCC GGCGCCAGAG GCCCGGCCA	420
CCGCGCGCGC CCCCCGCCCG CACCGCCCG CGCGGGCCCG GGGGGCGGGG CTAACCCCTC	480
CCACCCCCCT TCACGCCCTC TCCGCCTTCC GCGCGCCTC GCCCTCCGCC TGCGCGTCAC	540
CGCAGAGCAC CTGGCGCGCC TGCCTGCG ACAGCGGGC GGGGAGGGGG CGCCGGAGCC	600
CCCCCGGACCC CCCGCGACCC CGCGACCCCC CGACCCCCCG CGACCCCCCG	660
GACCCCCGCG ACCCCCGCGA CCCCCGCGAC CCCCCGCGGG GTGCGCTTCT CGCCCCACGT	720
CCGGGTGCGC CACCTGGTGG TCTGGCCCTC GGCGCCCGCC CTGGCGCGCC GCAGCTCGTG	780
GGCCCGCGAG CGGGCCGACC GGGCTCGGTT CGGGCGCCGG GTGGCGGAGG CCGAGGGCGGT	840
CATCGGGCCG TGCCTGGGCC CCGAGGCCCG TGCCCGGGCC CTGGCCCGCG GAGCCGGCCC	900
GGCGAAACTCG GTCTAACGTT ACACCCGAGG CGGCCTGGGT CTTCCCGCGA GCTCCCGGGGA	960
GCTCCGCACC AAGCCGCTCT CGGGAGAGAC GATGGCAGGA GCCGCGCATA TATACGCTGG	1020
GAGCCGGCCC GCCCCCGAGG CGGGCCCGCC CTCGGAGGGC GGGACTGGCC AATCGGCGGC	1080

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CGCCAGCGCG	GCGGGGCCCG	GCCAACCAGC	GTCCGCGAG	TCTTCGGGGC	CCGGCCCCACT	1140
GGGGGGGAGT	TACCGCCCAG	TGGGCCGGGC	CGCCCACCTTC	CCGGTATGGT	AATTAAAAAAC	1200
TTACAAGAGG	CCTTGTTCCG	CTTCCCGGTA	TGGTAATTAG	AAACTCATTA	ATGGCGGGCC	1260
CCGGCCGCC	TTCCCGCTTC	CGGCAATTCC	CGCGGCCCTT	AATGGGCAAC	CCCGGTATT	1320
CCCGCCT						1327

## (2) INFORMATION FOR SEQ ID NO:37:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 1292 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:37:

TTTAAAGCGG	TGGCGGCGGG	CAGCCCGGGC	CCCCCGCCGA	GACTAGCGAG	TTAGACAGGC	60
AAGCACTACT	CGCCTCTGCA	CGCACATGCT	TGCCTGTCAA	ACTCTACCAC	CCCGGCACGC	120
TCTCTGTCTC	CATGGCCCCG	CGCCGCCGCC	ATCGCGGCC	CCGCCGCC	CGGCCGCC	180
GGCCCACGGG	CGCCGTCCC	ACCGCACAGT	CCCAGGTAAC	CTCCACGCC	AACTCGGAAC	240
CCGCGGTCA	GAGCGCGCCC	CGGGCCGCC	CGCCGCC	CCCCGCC	GGGCCCCCGC	300
CTTCTTGTTC	GCTGCTGCTG	CGCCAGTGGC	TCCACGTTCC	CGAGTCCGCG	TCCGACGACG	360
ACGATGACGA	CGACTGGCCG	GACAGCCCCC	CGCCCGAGTC	GGGCCAGAG	GCCCCGCCA	420
CCGCCGCC	CCCCGCC	CCGGGCCCC	ACCGGCC	GTGGGCC	GGGGCGGGG	480
TGACCCCTCC	CACCCCCCT	CGCGCCCTT	CCGCCTTCCG	CCGCGCCTCG	CCCTCCGCCT	540
GCGCGTCACC	GCGGAGCACC	TGGCGCGCT	GCGCCTGCA	CGCGCGGCG	GGGAGGGGG	600
GCGGAGCCC	CCCGCGACCC	CCCGCACCCC	CGCGACCCC	GCGACCCC	CGACCCC	660
GACCCCCGCG	CGGGTGC	TCTCGCCCCA	CGTCCGGGTG	CGCCACCTGG	TGGTCTGGG	720
CTCGCCGCC	CGCCTGGCG	GCCGCGCTC	GTGGGCC	GAGCGGGCG	ACCGGGCTCG	780
GTTCCGGCGC	CGGGTGGCGG	AGGCGAGGC	GGTCATCGG	CCGTGCCTGG	GGCCCGAGGC	840
CCGTGCCCCG	GCCCTGGCCC	GCGGAGGCCG	CCCGCGAAC	TCGGTCTAAC	GTTACACCCG	900
AGGCGGCCTG	GGTCTTCCGC	GGAGCTCCCC	GGAGCTCCGC	ACCAAGCCGC	TCTCCGGAGA	960
GACGATGGCA	GGAGCGCGC	ATATATACGC	TTGGAGCCAG	CCCGCCCTCA	CAGGGCGGGC	1020
CGGGCGGGAC	TGGCAATCG	GCGGCCGCCA	CGCGCGGG	GCCGGCCAA	CCAGCGTCCG	1080
CCGAGTCTTC	GGGGCCCGGC	CCATTGGCG	GGAGTACCG	CCCAATGGG	CGGGCGCCC	1140
ACTTCCCGGT	ATGGTAATTA	AAAATTGCA	AGAGGCCTTG	TTCCGCTTCC	CGGTATGGTA	1200
ATTAGAAACT	CATTAATGGG	CGGCCCGGC	CGCCCTTCCC	GCTTCCGGCA	ATTCCCGCGG	1260
CCCTTAATGG	GCAACCCCGG	TATTCCCCGC	CT			1292

## (2) INFORMATION FOR SEQ ID NO:38:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 1280 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:38:

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TTTAAAGTCA CAGCGGGGGG CAGCCCCCCC GCGGCCGAGA CTAGCGAGTT AGACAGGCAA	60
GCACTACTCG CCTCTGCACG CACATGCTTG CCTGTAAAC TCTACCACCC CGGCACGCTC	120
TCTGTCTCCA TGCCCCGCCG CGCCGCCGC CATCGCGGCC CCCGCCGCC CGGGCCGCC	180
GGGCCAACGG GCGCGGTCCC AACCGCACAG TCCCAGGTA CCTCCACGCC CAACTCGAA	240
CCCGTGGTCA GGAGCGGCC CGCGGCCGGT GGGCCCCCGC CTTCTTGTTC GCTGCTGCTG	300
CGCCAGTGGC TCCACGTTCC CGAGTCCGCG TCCGACGAG ACGATGACGA CGACTGGCCG	360
GACAGCCCCC CGCCCGAGCC GGCCCCAGAG GCCCCGCCA CGCCGCCGC CCCCGCCCC	420
CACCGCCCGG CGCGGGCCCG GGGGGCGGGG CTAACCCCTC CCACCCCCCC TCACGCCCT	480
TCCGCCCTCC GCCGCGCCTC GCCCTCCGCC TGCGCGTCAC CGCGGAGCAC CTGGCGGCC	540
TGCGCCTGCG ACCGCGGGGC GGGGAGGGGG CGCCGAAGCC CCCCGGACCC CGCGGACCC	600
CCCGGACCCCC CGCGACCCCCC GCGACCCCCCG CGACCCCCCG GACCCCCGGG CGGGTGCCT	660
TCTCGCCCCA CGTCCGGGTG CGCCACCTGG TGGTCTGGGC CTGGCCGCC CGCCCTGGCGC	720
GCCGCGGCTC GTGGGCCCCG GAGCGGGCCG ACCGGGCTCG GTTCCGGCGC CGGGTGGCGG	780
AGGCCGAGGC GGTCATCGGG CCGTGCCTGG GGCCCGAGGC CGGTGCCCGG GCCCTGGCCC	840
GCGGAGCCGG CCCGGCAAC TCGGTCTAAC GTTACACCCG AGGCGGCGCTG GGTCTTCCGC	900
GGAGCTCCCG GGAGCTCCAC ACCAAGCCGC TCTCCGGAGA GACGATGGCA GGAGCCGCGC	960
ATATATACGC TGGGAGCCGG CCCGCCCCCG AGGCGGGCCC GCCCTCGGAG GCGGGACTG	1020
GCCAATCGGC GGGCGCCAGC GCGGGGGGGC CGGGCCAACC AGCGTCCGCC GAGTCGTGG	1080
GGCCCGGGCC ACTGGGGCGGT AACTCCCGCC CAGTGGGGCG GGCCGCCAC TTCCCGGTAT	1140
GGTAATTAAA AACTTGCAAG AGGCCTTGTG CCGCTTCCCG GTATGGTAAT TAGAAACTCA	1200
TTAATGGCG GCCCGGGCGC CCCTTCCGC TTCCGGCAAT TCCCGGGCC CTTAATGGC	1260
AACCCGGTA TTCCCCGCC	1280

## (2) INFORMATION FOR SEQ ID NO:39:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 1300 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:39:

TTTAAAGCGC GGCGGGGGC AGCCCCCCC CGGCCGAGAC TAGCGAGTTA GACAGGCAAG	60
CACTACTCGC CTCTGCACGC ACATGCTTG CTGTAAACT CTACCACCC CGGCACGCTC	120
CTGTCTCCAT GGCCCCGCCG CGCCGCCGC ATCGCGGCC CGCCGCCCG CGGCCGCC	180
GGCCCACGGG CGCGGTCCCA ACCGCACAGT CCCAGGTAAC CTCCACGCC AACTCGAAC	240
CCGTGGTCAG GAGCGCGCCC GCGGCCGCC CGCCGCCGCC CCCCGCCGGT GGGCCCCCGC	300
CTTCTTGTTC GCTGCTGCTG CGGCAGTGGC TCCAGGTTCC GGAGTCCCGC TCCGACGACG	360
ACGATGACGA CGACTGGCCG GACAGCCCC CGCCCGAGCC GGCGCCAGAG GCGCCGCCA	420
CCGCCGCCGC CCCCGCCCG CACCGCCCG CGCGGGCCCA GGGGGCGGGG CTGACCCCTC	480
CCACCCCCCC TCACGCCCTC TCCGCCCTCC GCCGCGCCTC GCGCCCGGCC TGCGCGTCAC	540
CGCAGAGCAC CTGGCGCGCC TGCGCCTGCG ACGCGCGGGC GGGGAGGGGG CGCCGGAGCC	600
CCCCGGACCC CGCGCGACCC CGCGACCCCC CGCGACCCCC CGACCCCCCG CGACCCCCGC	660

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GACCCCCCGCG CGGGTGCCT	TCTCGCCCCA CGTCGGGTG CGCCACCTGG	TGGTCTGGC	720
CTCGGCCGCC CGCCTGGCGC	GCCGCGGCTC GTGGGCCCGC GAGCGGGCCG ACCGGGCTCG		780
GTTCCGGCGC CGGGTGGCGG	AGGCCGAGGC GGTCATCGGG CCGTGCGCTGG	GCCCCAAGGC	840
CCGGCGCCGG GCCCTGGCCC	GCGGAGCCGG CCCGGCGAAC TCGGTCTAAC	GTTACACCCG	900
AGGCGGCCTG GGTCTTCCGC	GGAGCTCCCG GGAGCTCCAC ACCAAGCCGC	TCTCCGGAGA	960
GACGATGGCA GGAGCCGCGC	ATATATAACGC TGGGAGCCGG CCCGCCCCG AGGCAGGGCC		1020
GCCCTCGGAG GCGGGGACTG	GCCAATCGGC GGCGGCCAGC GCGGCGGGGC CCGGCCAAC		1080
AGCGTCCGCC GAGTCGTCGG	GGCCCGGCC ACTGGGCGGT AACTCCGCC CAGTGGGCCG		1140
GGCCGCCAAC TTCCCGGTAT	GGTAATTAAA AACTTGCAAG AGGCCTTGT	CCGCTTCCCG	1200
GTATGGTAAT TAGAAACTCA	TTAATGGCG GCCCCGGCG CCCTTCCCGC TTCCGGCAAT		1260
TCCCGCGGCC CTTAATGGC	AACCCCGGTA TTCCCCGGCT		1300

## (2) INFORMATION FOR SEQ ID NO:40:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 264 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:40:

Met Ala Arg Arg Arg His Arg Gly Pro Arg Arg Pro Arg Pro Pro			
1	5	10	15
Gly Pro Thr Gly Ala Val Pro Thr Ala Gln Ser Gln Val Thr Ser Thr			
20	25	30	
Pro Asn Ser Glu Pro Ala Val Arg Ser Ala Pro Ala Ala Ala Pro Pro			
35	40	45	
Pro Pro Pro Ala Ser Gly Pro Pro Pro Ser Cys Ser Leu Leu Leu Arg			
50	55	60	
Gln Trp Leu His Val Pro Ala Glu Ser Ala Ser Asp Asp Asp Asp Asp			
65	70	75	80
Asp Asp Trp Pro Asp Ser Pro Pro Pro Glu Pro Ala Pro Glu Ala Arg			
85	90	95	
Pro Thr Ala Ala Ala Pro Arg Pro Ser Pro Pro Pro Gly Ala Gly			
100	105	110	
Pro Gly Gly Gly Ala Asn Pro Ser His Pro Pro Ser Arg Pro Phe Arg			
115	120	125	
Leu Pro Pro Arg Leu Ala Leu Arg Leu Arg Val Thr Ala Glu His Leu			
130	135	140	
Ala Arg Leu Arg Leu Arg Arg Ala Gly Gly Glu Gly Ala Pro Glu Pro			
145	150	155	160
Pro Ala Thr Pro			
165	170	175	
Ala Thr Pro Ala			
180	185	190	
Arg Val Arg Phe Ser Pro His Val Arg Val Arg His Leu Val Val Trp			
195	200	205	
Ala Ser Ala Ala Arg Leu Ala Arg Arg Gly Ser Trp Ala Arg Glu Arg			
210	215	220	
Ala Asp Arg Ala Arg Phe Arg Arg Val Ala Glu Ala Glu Ala Val			

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225	230	235	240
Ile Gly Pro Cys Leu Gly Pro Glu Ala Arg Ala Arg Ala Leu Ala Arg			
245	250	255	
Gly Ala Gly Pro Ala Asn Ser Val			
260			

## (2) INFORMATION FOR SEQ ID NO:41:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 355 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:41:

Met Ala Arg Arg Arg Arg His Arg Gly Pro Arg Arg Pro Arg Pro Pro			
1	5	10	15
Gly Pro Thr Gly Ala Val Pro Thr Ala Gln Ser Gln Val Thr Ser Thr			
20	25	30	
Pro Asn Ser Glu Pro Ala Val Arg Ser Ala Pro Ala Ala Ala Pro Pro			
35	40	45	
Pro Pro Pro Ala Gly Gly Pro Pro Pro Ser Cys Ser Leu Leu Leu Arg			
50	55	60	
Gln Trp Leu His Val Pro Glu Ser Ala Ser Asp Asp Asp Asp Asp Asp			
65	70	75	80
Asp Trp Pro Asp Ser Pro Pro Glu Ser Ala Pro Glu Ala Arg Pro			
85	90	95	
Thr Ala Ala Ala Pro Arg Pro Pro Gly Pro His Arg Pro Ala Trp Ala			
100	105	110	
Arg Gly Ala Gly Leu Thr Pro Pro Thr Pro Pro Arg Ala Pro Ser Ala			
115	120	125	
Phe Arg Arg Ala Ser Pro Ser Ala Cys Ala Ser Pro Arg Ser Thr Trp			
130	135	140	
Arg Ala Cys Ala Cys Asp Ala Arg Ala Gly Arg Gly Arg Arg Ser Pro			
145	150	155	160
Pro Arg Pro Pro Arg Pro Pro Arg Pro Pro Pro Arg Pro Pro Pro			
165	170	175	
Arg Gly Cys Ala Ser Arg Pro Thr Ser Gly Cys Ala Thr Trp Trp Ser			
180	185	190	
Gly Pro Arg Pro Pro Ala Trp Arg Ala Ala Ala Arg Gly Pro Ala Ser			
195	200	205	
Gly Pro Thr Gly Leu Gly Ser Gly Ala Gly Trp Arg Arg Pro Arg Arg			
210	215	220	
Ser Ser Gly Arg Ala Trp Gly Pro Arg Pro Val Pro Gly Pro Trp Pro			
225	230	235	240
Ala Glu Pro Ala Arg Arg Thr Arg Ser Asn Val Thr Pro Glu Ala Ala			
245	250	255	
Trp Val Phe Arg Gly Ala Pro Gly Ser Ser Ala Pro Ser Arg Ser Pro			
260	265	270	
Glu Arg Arg Trp Gln Glu Pro Arg Ile Tyr Thr Leu Gly Ala Ser Pro			
275	280	285	
Pro Ser Gln Gly Gly Pro Pro Arg Gly Arg Asp Trp Pro Ile Gly Gly			
290	295	300	
Arg Gln Arg Gly Gly Ala Arg Pro Thr Ser Val Arg Arg Val Phe Gly			

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305	310	315	320
Ala Arg Pro Ile Gly Arg Glu Leu Pro Pro Asn Gly Pro Gly Arg Pro			
325	330	335	
Leu Pro Gly Met Val Ile Lys Asn Leu Gln Glu Ala Leu Phe Arg Phe			
340	345	350	
Pro Val Trp			
355			

## (2) INFORMATION FOR SEQ ID NO:42:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 245 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:42:

Met Ala Arg Arg Arg Arg Arg His Arg Gly Pro Arg Arg Pro Arg Pro			
1	5	10	15
Pro Gly Pro Thr Gly Ala Val Pro Thr Ala Gln Ser Gln Val Thr Ser			
20	25	30	
Thr Pro Asn Ser Glu Pro Val Val Arg Ser Ala Pro Ala Ala Gly Gly			
35	40	45	
Pro Pro Pro Ser Cys Ser Leu Leu Leu Arg Gln Trp Leu His Val Pro			
50	55	60	
Glu Ser Ala Ser Asp Asp Asp Asp Asp Asp Trp Pro Asp Ser Pro			
65	70	75	80
Pro Pro Glu Pro Ala Pro Glu Ala Arg Pro Thr Ala Ala Ala Pro Arg			
85	90	95	
Pro Arg Ser Pro Pro Pro Gly Ala Gly Pro Gly Gly Ala Asn Pro			
100	105	110	
Ser His Pro Pro Ser Arg Pro Phe Arg Leu Pro Pro Arg Leu Ala Leu			
115	120	125	
Arg Leu Arg Val Thr Ala Glu His Leu Ala Arg Leu Arg Leu Arg Arg			
130	135	140	
Ala Gly Gly Glu Gly Ala Pro Lys Pro Pro Ala Thr Pro Ala Thr Pro			
145	150	155	160
Ala Thr Pro Ala Thr Pro Ala Thr Pro Ala Arg Val Arg			
165	170	175	
Phe Ser Pro His Val Arg Val Arg His Leu Val Val Trp Ala Ser Ala			
180	185	190	
Ala Arg Leu Ala Arg Arg Gly Ser Trp Ala Arg Glu Arg Ala Asp Arg			
195	200	205	
Ala Arg Phe Arg Arg Val Ala Glu Ala Glu Ala Val Ile Gly Pro			
210	215	220	
Cys Leu Gly Pro Glu Ala Arg Ala Arg Ala Leu Ala Arg Gly Ala Gly			
225	230	235	240
Pro Ala Asn Ser Val			
245			

## (2) INFORMATION FOR SEQ ID NO:43:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 252 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single

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(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:43:

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Met Ala Arg Arg Arg Arg His Arg Gly Pro Arg Arg Pro Arg Pro
1           5          10          15

Pro Gly Pro Thr Gly Ala Val Pro Thr Ala Gln Ser Gln Val Thr Ser
20          25          30

Thr Pro Asn Ser Glu Pro Val Val Arg Ser Ala Pro Ala Ala Ala Pro
35          40          45

Pro Pro Pro Ala Gly Gly Pro Pro Pro Ser Cys Ser Leu Leu Leu
50          55          60

Arg Gln Trp Leu Gln Val Pro Glu Ser Ala Ser Asp Asp Asp Asp
65          70          75          80

Asp Asp Trp Pro Asp Ser Pro Pro Glu Pro Ala Pro Glu Ala Arg
85          90          95

Pro Thr Ala Ala Ala Pro Arg Pro Arg Ser Pro Pro Pro Gly Ala Gly
100         105         110

Pro Gly Gly Ala Asp Pro Ser His Pro Pro Ser Arg Pro Phe Arg
115         120         125

Leu Pro Pro Arg Leu Ala Leu Arg Leu Arg Val Thr Ala Glu His Leu
130         135         140

Ala Arg Leu Arg Leu Arg Arg Ala Gly Gly Glu Gly Ala Pro Glu Pro
145         150         155         160

Pro Ala Thr Pro Ala Thr Pro Ala Thr Pro Ala Thr Pro
165         170         175

Ala Thr Pro Ala Arg Val Arg Phe Ser Pro His Val Arg Val Arg His
180         185         190

Leu Val Val Trp Ala Ser Ala Ala Arg Leu Ala Arg Arg Gly Ser Trp
195         200         205

Ala Arg Glu Arg Ala Asp Arg Ala Arg Phe Arg Arg Val Ala Glu
210         215         220

Ala Glu Ala Val Ile Gly Pro Cys Leu Gly Lys Glu Ala Arg Ala Arg
225         230         235         240

Ala Leu Ala Arg Gly Ala Gly Pro Ala Asn Ser Val
245         250

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What is claimed is:

1. A method of treating tumorigenic disease of the central nervous system in a mammal comprising the step of administering at or near a site of a tumor of said tumorigenic disease a herpes simplex virus vector lacking expressible  $\gamma_134.5$  genes.

2. The method of claim 1 wherein the  $\gamma_134.5$  gene comprises a stop codon in reading frame.

3. The method of claim 1 wherein the  $\gamma_134.5$  gene comprises a deletion mutation.

4. The method of claim 1 wherein the herpes simplex virus vector is HSV-1.  
 5. The method of claim 1 wherein the herpes simplex virus vector is HSV-2.  
 6. The method of claim 1 wherein the herpes simplex virus vector is administered via direct injection into said tumor of said tumorigenic disease.

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